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1910.

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**THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.**

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## Iceland Minerals.

I have just received after considerable delay a new lot of Iceland Zeolites consisting of one hundred specimens. The species represented are Heulandite, Stilbite, Epistilbite, Scolecite, Ptilolite and Quartz geodes in both Museum and cabinet size specimens, which I have priced at far below former values placed on these choice trap rock minerals. Their beauty, brilliancy and the quality of the crystals is finer than any former lot brought to this country.

## Minerals from Franklin Furnace, N. J.

I have also been fortunate in obtaining a very old collection from a gentleman who specialized in Franklin Furnace minerals and which contains many duplicates of finely crystallized specimens. For instance, several of the extremely rare crystallized Zincites as well as Franklinites, Rhodonites, Troostites in very large crystals; also Gahnite, Tourmaline, Calamine, Garnet and Spinel. An exceptional lot of choice Phlogopite in Calcite of the largest size found.

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THE  
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[FOURTH SERIES.]

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ART. I.—*Dinosaurian Distribution*; by RICHARD S. LULL.

[Contribution from the Paleontological Laboratory, Peabody Museum,  
Yale University.]

- I. Introductory.
- II. Classification.
- III. Habitats and adaptations.
- IV. Geological distribution.
- V. Geographical distribution.
- VI. Summary of migrations and palæogeography.
- VII. Bibliography.

*Dinosaurian Distribution.*

I. INTRODUCTORY.

THE significance of terrestrial vertebrates of bygone days as aids to geological interpretation, and especially in throwing light upon the isolation and connection of continents, is becoming more and more appreciated.

The dinosaurs, with their known geological range throughout nearly the entire Mesozoic period, and of almost world-wide distribution, are the most significant vertebrates of Secondary times. Add to this their great numbers both of individuals and kinds and the amazing range in their adaptations and one can appreciate the importance of the line of research of which this paper is the first fruit. It constitutes the further elaboration of a presidential address delivered before the American Society of Vertebrate Paleontologists at Baltimore, December, 1908.

As such a work is of necessity to a certain extent a compilation, I can but express my indebtedness to the various authors listed in the Bibliography, of whom my confrère, Professor v. Huene, is the one to whom I owe the most. I am also

AM. JOUR. SCI.—FOURTH SERIES, VOL. XXIX, No. 169.—JANUARY, 1910.



grateful to my colleagues Professors Schuchert and Barrell for helpful criticisms and suggestions.

## II. CLASSIFICATION.

The dinosaurs, because of their great adaptive radiation throughout their long career, seem to be a very heterogeneous group, so much so that Baur (1891) emphatically denied any relationship on the part of the several orders which are included within the group.

They exhibit two distinct lines of cleavage, dividing the super-order into three orders, of which two, the carnivorous, bipedal Theropoda and the herbivorous, quadrupedal Sauropoda, may be grouped together, in spite of great adaptive differences; while the herbivorous, bipedal or quadrupedal Orthopoda stand more aloof and show a vastly greater range of intra-ordinal variation. To the first two orders collectively the name Saurischia has been given by Seeley (1888), while the Orthopoda have been designated by the corresponding title of Ornithischia.

A further differentiation of the Theropoda points to two distinct races. The heavier megalosaurs, typified by *Megalosaurus* of Europe, *Allosaurus* of the American Morrison, and culminating in the huge *Tyrannosaurus* of the Laramie, were the more conservative group, the evolution of which consists mainly in an increase in size, accompanying a relative diminution of the fore limbs, which were never used for locomotion, and an assumption of the prehensile function by hind feet and mouth armament as in birds of prey.

The other carnivores, the compsognathoid forms, were of an aberrant nature, not increasing so markedly in size; but of a more agile character, better fitted to prey upon feebler reptiles, birds and mammals than upon other dinosaurs. Typical members of this sub-order are *Compsognathus* from the lithographic stone of Bavaria and *Ornitholestes* of the American Morrison beds.

The Sauropoda appear and disappear with startling suddenness in the northern hemisphere, though lingering in the southern until the close of the Mesozoic. During this time they undergo but little evolution, and that mainly in the line of a marvelous adaptation for lightness coupled with great strength, especially in the elongated vertebral column. Perhaps the best-known representatives of this group are *Apatosaurus* (*Brontosaurus*), a huge, unwieldy beast, and *Diplodocus*, a lighter, more slender form; both from the Morrison of Wyoming and Colorado. It is a significant fact that the most generalized (*Haplocanthosaurus*) and the most specialized

(*Diplodocus*) among sauropods occur in the same quarry and were therefore contemporaneous. (Hatcher 1903, p. 57).

Of the plant-feeding Orthopoda there are three main types, which have differentiated from the original stock; one, the unarmored Ornithopoda, paralleling the carnivores in general bodily contour and bipedal gait, though bringing the fore feet to the ground when occasion demanded. Like the carnivores they too included a greater and a lesser race. The former, like *Iguanodon* of the Wealden of Europe and *Campotossaurus* of the American Morrison, culminated in *Trachodon* of the late Cretaceous; while the latter are represented by the fleet *Laosaurus* of North America and *Hypsilophodon* of Europe.

On the other hand, two groups of armored, secondarily quadrupedal dinosaurs arose, possibly derived from the same branch of the Orthopoda, possibly of independent origin. These were the Stegosauria, the defensive sort with small head and heavy body armor sometimes forming, over part of the body at least, a veritable cuirass or carapace; and the more aggressive Ceratopsia with huge armored skull, but, so far as our knowledge goes, bereft of any special body mail. The first are represented by the British *Polacanthus* and the American *Stegosaurus*, while the last have a splendid representation in that most grotesque of dinosaurs, *Triceratops* from the American Laramie.

V. Huene (1907–1908, p. 351) derives the Sauropoda from the early Theropod dinosaurs of the Trias, seeing in the genus *Plateosaurus* the annectant type. In his scheme of relationships (v. Huene 1909, p. 22), however, he seems to defer the divergence of the Sauropoda from the Plateosauridæ until the Lias, which would hardly give time for the profound change shown by either *Cetiosaurus* or *Dystrophæus* of the Dogger. It is my impression that the divergence occurred earlier in Triassic time.

Of annectant forms, linking the Theropoda and Orthopoda, none is suggested by v. Huene among known types, as our known record of the latter does not go back far enough in time. Of the Stegosauria, *Scelidosaurus* of the English Lias seems to be the most primitive as it surely is the oldest; it is, however, still removed from the Ornithopoda and a common ancestor must again be sought in more remote strata.

The Ceratopsia may have their earliest representative in *Stenopelix* of the Wealden of Brückeburg. V. Huene (1907–1908, p. 374) has shown strong points of resemblance between the pelvis of *Stenopelix* and that of *Triceratops*. Whether, as he suggests, one can derive the phylum from the Scelidosauridan stem, or whether the group represents an independent offshoot from the Orthopod stock, is not quite clear.

These relationships are expressed in the table (figure 1), which is largely compiled from lesser ones by v. Huene (1907-1908, pp. 340, 375, 377; 1909, p. 22).

### III. HABITATS AND ADAPTATIONS.

In order to comprehend the remarkable geographical distribution of the dinosaurs, it is necessary to investigate the character of their various habitats, the conditions they were forced to meet and the marvelous degree of adaptation to the environment which they underwent.

I imagine the conditions which gave to the dinosaurs their initial evolutionary trend were such as are thought to have prevailed, beginning in the Permian, throughout Triassic time. This is well shown in the region now known as the Connecticut valley. The older notion of the estuarine origin of these deposits has been abandoned in favor of the idea that they were of terrestrial origin, the climatic conditions being those of semi-aridity with areas here and there which were subject to inundations occurring in times of torrential rains such as are observed to-day under similar climatic conditions in different portions of our globe. This lends color to the view that the early dinosaurs were truly terrestrial types, with marked cursorial adaptation, indicated in the free, bipedal stride and compact, bird-like foot which is shown by the fossil footprints.

V. Huene (1907-1909, pp. 396-401) derives the Theropoda and Parasuchia from one stem, the supposition being that the distinguishing characteristics were developed during the oldest Trias through adaptation. Increasing aridity of climate would render it necessary for an animal to go farther afield for water and possibly for food and thereby place a premium on good powers of locomotion, so that selection would be very active in weeding out the unfit or inadaptable lines. This locomotor adaptation in the quadrupedal stage is beautifully shown in the Parasuchian genus *Stegomus* (Lull 1904 B, pp. 147-148) from the Connecticut valley Trias (Rhætic), evidently a persistent type which, possibly because of the retention of armor, remained a quadruped though long of limb and with the greater portion of the weight borne on the hinder extremities. *Stegomus*, I imagine, though belonging, morphologically, to a very different race, represents a stage in the adaptation of the dinosaurs which was reached early in the Trias.

Many modern lizards are amazingly swift of movement, but their journeys are brief and the rapidly moving types are small. It is a well known fact that a number of lizards, notably *Chlamydosaurus*, when startled, rise on the hinder limbs

and run with a truly bipedal gait (Sayville-Kent 1898, p. 341). It is significant that the bipedal lizards, so far as my knowledge goes, are all found in semi-arid climates—Australia, Southwestern United States. This tendency toward bipedalism, with a consequent profound alteration of the hind limbs and pelvis, both in bone and musculature, seems therefore to have developed to meet the need of greater range of movement necessitated by increasing aridity, and was the prime factor in the early evolution of the dinosaurian race.

So strongly was this feature impressed, that the main lines of dinosaurian evolution, whether plant or animal feeders, were cursorial, terrestrial types, though, as new conditions arose, or were met with during their forced migrations, aberrant types of marvelous complexity and range of specialization developed. These aberrant forms, from the fact that their remains were more readily preserved, are the ones best known to us and have colored our whole conception of the dinosaurian race.

When the plant-feeding Orthopoda arose we do not know. *Nanosaurus* (v. Huene and Lull 1908) is known from the upper Trias (or lower Jurassic) of Colorado, while in the possibly contemporaneous beds of the Connecticut valley there have been found many footprints which Lull (1904 A, pp. 499–509) has shown to belong to plant-feeding types of general proportions not unlike those of their theropod allies, but differing mainly in the feebly prehensile character of the little, blunt-toed manus, the imprint of which is sometimes seen. The Theropoda, on the other hand, had a strong, grasping hallux, as a rule rotated to the rear of the foot so as to be in opposition to the other toes, and a manus with powerful claws, which had already sacrificed fully the function of locomotion to that of prehension. The Orthopoda could give rise to secondarily quadrupedal (Dollo 1905) forms, the Stegosauria, the Ceratopsia; the Theropoda, on the other hand, had cast the die in favor of absolute bipedalism and stalked on upon the hind limbs to the end of their career.

While both small and large forms prevailed at the close of the Trias, the differentiation, if we except the character of the pubis, is largely owing to opposite habits, acquired apparently in the remote Trias, very early in the dinosaurian evolution.

The carnivores, as has been said, are relatively conservative in their evolution, except for the differentiation into the greater megalosauroid forms and the lesser compsognathoid types. The Theropoda were evidently the most mobile of all dinosaurs, free to migrate wherever other creatures lived which could possibly be utilized for prey, for not only do we find them the world over, with the exception of Asia (vide

infra p. 31) north of India, but practically wherever dinosaurs of whatever sort are found.

### *The Sauropoda.*

During the Triassic, the carnivores had spread to other conditions and had given rise to a new order, the Sauropoda, no longer truly terrestrial, but inhabiting the bayous and swamps of the numerous deltas which fringed the continental shores. This change of habitat was far-reaching in its effects, for rapid locomotion was no longer necessary and a certain degeneracy resulted—whether the carnivorous ancestors had attained bipedalism or whether the Sauropoda were primitively quadrupedal I cannot say. Increase in size was accompanied by an elongation of the neck to get a greater range of feeding with as little bodily movement as possible and it necessitated as well a diametric change in diet, for with increasing bulk, no longer finding the animal food of their forbears adequate or readily obtainable, they took to an herbivorous feeding habit which required but little change in the mouth armament.

The modern Iguanidæ show a certain parallelism with the Sauropoda, for while the primitive diet is carnivorous (insectivorous) “some of the most striking forms are herbivorous, e. g. *Iguana*, *Amblyrhynchus*, and *Basiliscus*.” (Gadow 1908, pp. 528, 533.) Moreover, one finds within the family not only semi-aquatic adaptation, but even semi-marine. The last is shown by *Amblyrhynchus cristatus*, which “inhabits the rocky and sandy strips of coast of most of the Galapagos Islands, feeding on certain kinds of algae, which it has to dive for, since these plants grow below tide-marks.”

The precise food of the Sauropoda is a matter of doubt. Dr. Hay (1908, p. 674), in discussing that of *Diplodocus*, the most highly specialized member of the order, sums up the expressions of opinion as follows: “Hatcher suggested that the teeth might have been useful in detaching from the bottoms and shores the succulent aquatic and semi-aquatic plants that must have grown there in abundance. Osborn [1889, p. 214] says that the ‘food probably consisted of some very large and nutritious species of water plant. The anterior claws may have been used in uprooting such plants \* \* \* The plants may have been drawn down the throat in large quantities without mastication.’ \* \* \* Holland [1906, p. 240] thinks that the teeth were better adapted for raking and tearing off from the rocks soft masses of clinging algæ than for securing any other forms of vegetable food now represented in the waters of the world.

"To the present writer [Hay] the suggestion of Dr. Holland has in it more of probability than any of the others presented. If the food-plants sought by *Diplodocus* had been large and such as required uprooting by the great claws of the reptile, the prehension and manipulation of the masses would have been liable to break the slender teeth and would certainly have produced on them perceptible wear. \* \* \*

"It is more probable that the food consisted of floating algae than of plants that were loosely attached to the bottoms of stagnant bayous and ponds. . . . In addition to various algae were probably other floating plants."

The teeth of the Sauropoda, notably *Morosaurus* and *Aptosaurus* (*Brontosaurus*), are much more robust and frequently show decided wear. This wear, however, is along the edges on either side of and sometimes including the apex; which could readily be accounted for by abrasion of the alternating teeth of the opposing jaw and which could not be due to scraping of vegetation from the rocks. The food of these animals may have been more in keeping with the character of that mentioned by Osborn.

It is interesting to note in this connection, à propos of the question of the digestibility of huge masses of unmasticated vegetation, the occurrence of "stomach stones" or "gastroliths" (Wieland 1906) which seem to have had an important function in aiding in the trituration of the food. Wieland records the occurrence of such polished flint pebbles in immediate association with the remains of a large sauropod observed at the northern end of the Big Horn Mountains. Pebbles, presumably gastroliths, were also found by Wieland with the type of the Sauropod genus *Barosaurus* from near Piedmont, South Dakota.

Dr. Hay (loc. cit., p. 673-674) further says: "Hatcher has discussed at length the nature of the region in which the species of *Diplodocus* and their allies lived, as well as the habits of the Sauropoda in general; and the present writer [Hay] agrees with him on most points. Hatcher believed that the *Atlantosaurus* [Morrison] beds were deposited, not in an immense freshwater lake, as held by some geologists, but over a comparatively low and level plain which was occupied by perhaps small lakes connected by an interlacing system of river channels. The climate was warm and the region was overspread by luxuriant forests and broad savannas. The area thus occupied included large parts of the present states of Colorado, New Mexico, Utah, Montana and the Dakotas. In his memoir on *Diplodocus* Hatcher compares the conditions prevailing in that region during the Upper Jurassic [Lower Cretaceous] to those now found about the

month of the Amazon and over some of the more elevated plains of Western Brazil.

"In such regions the rivers, fed from distant elevated lands, must have been subject to frequent inundations. The beds of the streams were continually shifting, and there existed numerous abandoned channels that were filled with stagnant water. An animal that lived in such a region would be compelled to adapt itself to a more or less aquatic life, and this adaptation would be reflected to a greater or less extent in the structure of the animal."

Through the courtesy of Dr. Holland, I have been able to study somewhat critically an undoubted sauropod footprint from the Morrison dinosaur quarry at Cañon City, Colorado. Hatcher figures a cast of this track in his memoir on the osteology of *Haplocanthosaurus* (1903, fig. 23, p. 161). The figure is somewhat deceptive, however, in that it was taken from a plaster cast of the specimen which in turn is a natural cast of the original impression made by the living animal and which is therefore in relief. The surface of the specimen itself is covered with deep pits caused by a solution of the calcareous cement which bound the grains of sand together, thus allowing the latter to be washed out. In the photograph the casts of these pits, being in relief, give the impression of pebbles, whereas the rock in the quarry is a fine-grained, cross-bedded sandstone of uniform texture, without appreciable clay, and not gravelly at all. A microscopic study of the sand-grains themselves show them to be angular with slightly abraded corners, sand of aqueous deposit; but apparently laid down in a lake or bayou, rather than in a normal river as indicated by the absence of clay and the presence of a lime cement. The cross-bedding which the rock exhibits could readily have been made by wave action along the shores of a comparatively shallow delta-lake or bay, and the track, which is that of a very young animal, was evidently made under water. The character of the sediment does not give evidence of much vegetable matter at the particular point where the track was made. The footprint is that which one would expect from the known character of the sauropod foot, and is evenly impressed throughout as though the animal's weight were borne equally over the entire sole, evidence in favor of a true walk rather than a sprawling crawl, at any rate when the body was partly water-borne.

I believe these animals to have been truly aquatic though capable of coming ashore where the substratum was sufficiently firm to support the immense weight, and, while they show no trace of swimming appendages, they doubtless could swim as a hippopotamus does or, as Hay (1908, p. 667) has implied, like a

colubrid snake "which makes fair progress in the water, notwithstanding the absence both of a compressed tail and of a vertical fin."

The Wealden formation of England is thus described by Geikie (1903, pp. 1180-1181). "The Purbeck beds bring before us evidence of a great change in the geography of England towards the close of the Jurassic period. They show how the floor of the sea, in which the thick and varied formations of that period were deposited, came to be gradually elevated, and how into pools of fresh and brackish water the land leaves, insects, and small marsupials of the adjacent land were washed down. These evidences of terrestrial conditions are followed in the same region by a vast delta formation, that of the Weald, which accumulated over the south of England, while the marine strata were being deposited in the north. Hence two types of Lower Cretaceous sedimentation occur, one where the strata are fluvial (Wealden), and the other where they are marine (Neocomian)."

In Wyoming the Morrison beds lie directly upon the marine *Baptanodon* beds of Marsh in which *Belemnites* abound. Lying between this and the main dinosaur-bearing layer are about 156 feet (Loomis 1901, pp. 192-193) of variegated sandstones and clays, of which bed No. 13, 82½ feet above that which contains *Baptanodon* itself, seems to represent the first of the freshwater (or brackish) series, as it contains an abandoned dinosaur quarry in Como Bluff. This would seem to indicate that in the Morrison, conditions very similar to that of the Wealden prevailed and that in each instance access to the sea on the part of the sauropod inhabitants was not only possible but actually probable, as the littoral realm seems to have been the highway of immigration of this order of dinosaurs.

The Morrison beds, lying as they do in a great synclinal trough, and at the time of their deposition but little above sea level, probably were drained, in the southern portion at least, into the sea, which lay some two hundred and fifty miles (Schuchert 1909, Late Upper Jurassic Chart) to the southward. This drainage outlet because of its very low gradient may again have given conditions similar to those of the Amazon (vide supra p. 8), so that the passage of the Sauropoda across the area included in the present state of New Mexico would appear to have been perfectly feasible. Evidence which may be corroborative is found in Madagascar, in a locality east of the bay of Narinda, wherein were discovered the remains of *Titanosaurus* in a matrix containing the marine *Mytilus madagascarensis* and foraminifera (Boule 1896, p. 348).



*Orthopoda.*

The Orthopod dinosaurs were adapted to a very different kind of food from that of the Sauropoda, developing in the course of their evolution a more and more perfect dental mechanism for chopping into short lengths the relatively firm terrestrial vegetation. The toothless anterior part of the mouth was sheathed in a leathery or horny beak which reached its highest perfection in the Ceratopsia and which constituted the prehensile, while the teeth, borne in the posterior portion of the jaws, formed the masticatory part of the mouth; best developed in the Ceratopsia (Hatcher 1907, pp. 43-46) on the one hand and the Trachodontidæ (Brown 1908, pp. 52-53) on the other.

The Sauropoda and Theropoda had only prehensile teeth and did not masticate their food at all. This shows quite clearly that, so far as feeding habits go, none of the three great groups of dinosaurs came into competition with each other, except that the carnivores did occasionally devour the others, and that, in so far as the Sauropoda and Orthopoda were concerned, the habitat was necessarily different; the latter being in the main terrestrial, the former amphibious. In no other way can we account for the marked differences in distribution of the two orders which, reduced to its final analysis, has gone so far that the two groups are rarely found in the same quarry even within the same region and geological formation. For example, "Quarry 13" (Gilmore, 1909, p. 299) in Como Bluff, Wyoming, from which several of Professor Marsh's more important type specimens came, contains almost entirely the remains of Orthopoda, *Camptosaurus*, *Dryosaurus*, *Stegosaurus*; of Carnivores, *Allosaurus* and *Cœlurus*, while but a single Sauropod, the type of *Morosaurus lentus*, an extremely young individual, was found in association. On the other hand, the famous Bone Cabin Quarry, situated but a few miles distant, had yielded up to 1904 (Osborn, 1904, p. 694) sauropods, 44; stegosaurs, 3; smaller herbivorous dinosaurs, 4; large carnivorous dinosaurs, 6; small carnivorous dinosaurs, 3; showing the Sauropoda to be vastly more numerous than the other plant-feeding varieties, and evidently implying a distinct habitat from that represented by "Quarry 13."

Within the Orthopoda the marked differentiation into Ornithopoda, or unarmored types, and the Stegosauria and Ceratopsia, or armored forms, seems to have been due to their different modes of defence, presumably against the omnipresent carnivores, though the existence of enemies other than dinosaurs, such as the crocodile *Goniopholis*, is not unlikely. The Ornithopoda, which were the most conservative in their evolu-

tion among the Orthopoda, retained the cursorial character of their ancestry, relying evidently upon celerity and speed rather than upon weapons or armor for defence against their sanguinary foes. The ideal of this type of dinosaur was perhaps *Laosaurus* of North American Morrison and its old world representative *Hypsilophodon* of the English Wealden. Later *Trachodon*, and probably its ancestor *Claosaurus*, the remains of which are found repeatedly in marine rocks, became in their turn semi-aquatic, possibly in their search for food because of competition with the great armored forms. They did not, however, rely on increasing bulk for immunity against attack as did the Sauropoda; but, by means of a powerful, laterally compressed swimming tail may have been as active as crocodiles in the water while still retaining a means of comparatively rapid locomotion on land. The defencelessness of these creatures, so far as armor is concerned, has been beautifully shown in the "mummified" specimen of *Trachodon*, discovered in 1908 by C. H. Sternberg, in Converse County, Wyoming, and now preserved in the American Museum of Natural History. Professor Osborn (1909, pp. 793-795) says of it: "The first and most surprising impression is that the epidermis is extremely thin, and that the markings are excessively fine and delicate for an animal of such large dimensions. There is no evidence in any part of the epidermis either of coarse tubercles or of overlapping scales. In all parts of the body observed it is entirely composed of scales of two kinds: (1) larger pavement or non-imbricating scales, (2) smaller tubercular scales." Osborn speaks not only of the "vigorous use of the tail as a balancing, and perhaps partly as a swimming organ," but also tells us that the "manus is completely encased in the integument, and was thus web-footed." Evidence for aquatic or semi-aquatic life.

The armored dinosaurs make their first appearance in *Scelidosaurus* of the English Lias, the possible ancestor of all of the subsequent mailed types. The earliest forms were probably bipedal, but, as time went on, and the armor increased in bulk and weight, we find these dinosaurs becoming secondarily quadrupedal (Dollo 1905), losing all celerity of movement and becoming sluggish, slow moving, living citadels of well-nigh impregnable character. In habitat they were doubtless terrestrial, as in the case of the earlier Ornithopoda with which their remains are found associated. A curious differentiation of armored dinosaurs occurred, correlated with a marked difference in the mode of defence, in that the more aggressive, mentally alert Ceratopsia used the head both for offence and defence, while the stegosaurs seem to have used the tail. *Stegosaurus* proper, which developed to an extreme this method

of defence as well as a remarkable body armament of huge probably upstanding plates, became too highly specialized to survive and apparently died out early in the Lower Cretaceous. Its allies, however, still lived on until the close of the Mesozoic, developing over the rear of the body in *Polacanthus* of the English Wealden, and later in *Ankylosaurus* of the Laramie, a veritable cuirass, glyptodon-like in its perfection, covering what seemed to be the most vulnerable portion of the body.

That the Ceratopsia were aggressive fighters among themselves, as the cattle are to-day, is known from the frequent punctures of skull and frill, broken horn-cores, and such sanguinary evidences. That they held their own against the terrible carnivores of their time is shown by their survival until the close of dinosaurian history.

The environment of the Cretaceous Orthopod dinosaurs and of the attendant carnivores is described by Stanton (1909, pp. 280-282) as consisting of great areas but slightly elevated above the level of the sea and occasionally actually beneath it, wherein are found fresh-water, brackish water, or marine deposits. Upon these great marshes vegetation became established, and land animals, and those of the streams and lagoons as well as the bays and estuaries, sought their appropriate habitats.

In speaking of the conditions prevailing toward the close of the Cretaceous, Hatcher (1893, p. 142; Hatcher, Marsh, Lull 1907, p. 194) says: "The Ceratops beds are thought to afford evidence in themselves of having been deposited not in a great open lake, but in a vast swamp with occasional stretches of open waters, the whole presenting an appearance similar to that which now exists in the interior of the Everglades of Florida. This condition would account for the frequent changes from one material to another in the same horizon.\* \* \*

"The conditions that prevailed over this region during the period in which the Ceratops beds were deposited were probably those of a great swamp with numerous small open bodies of water connected by a network of water courses constantly changing their channels. The intervening spaces were but slightly elevated above the water level or at times submerged. The entire region where the waters were not too deep was covered by an abundant vegetation, and inhabited by the huge dinosaurs (*Triceratops*, *Torosaurus*, *Claosaurus*, etc.), as well as by the smaller crocodiles and turtles and the diminutive mammals, all of whose remains are now found embedded in the deposits."

For the terrestrial Orthopoda, such as *Camptosaurus* and *Iguanodon*, the cycads and ferns which grew in such profusion during their time would supply ample nourishment. *Stegosau-*

rus, however, has relatively feeble teeth, and must have fed upon the most succulent of terrestrial plants. The Ceratopsia, living as they did toward the close of the Upper Cretaceous, were surrounded by a virtually modernized flora, and hence may have had feeding habits very similar to those of the sub-tropical browsing ungulates of to-day.

*Trachodon*, however, presents more of a problem on account of its undoubted aquatic habits. Here the anterior, toothless part of the mouth in the most highly specialized types became broadened and depressed into a duck-like form, and, while undoubtedly sheathed with a horny or leathery integument, probably did not have the shearing mechanism so perfectly developed as in the true terrestrial plant-feeders. On the other hand, the dental battery reaches its greatest perfection in *Trachodon*, consisting as it does of "from 45 to 60 vertical and from 10 to 14 horizontal rows of teeth, so that there were more than 2,000 teeth altogether in both jaws." (Brown, 1908, p. 53.) The immense number, especially of those in reserve, implies a very rapid wear and consequent replacement of the teeth; which, together with the sharp, serrated, shearing edge which the collective teeth of a jaw present, argues strongly in favor of the idea as expressed by Brown (loc. cit., p. 55) that some species of *Equisetæ*, the remains of which are the most abundant among the plant relics entombed with these dinosaurs, supplied them with food. The broad duck-like muzzle would be admirable for dislodging the rhizomes from their resting place, while the abundance of silica in the cuticle of the plant would necessitate just such a dental battery as the *Trachodonts* possessed for its proper mastication.

#### IV. GEOLOGICAL DISTRIBUTION.

Both geologically and geographically the dinosaurs show a peculiar discontinuous distribution, due in large measure to the imperfection of our records, but also to the fact that they were principally terrestrial types and that the preservation of their remains in water-laid rocks is largely the result of accident.

##### *Theropoda.*

Geologically the *Theropoda* have the greatest range, as they are first found in the Lower Muschelkalk of Europe and continue on until the end of the Mesozoic.

##### *Triassic.*

Of the Triassic forms, a very complete series is found in central Europe, of which one of the most primitive genera is *Thecodontosaurus*, which also had the widest distribution both geographically and in time (see fig 2). From the *Thecodonto-*

*saurus* stem are derived, as side lines, the Newark dinosaurs *Anchisaurus* and *Ammosaurus* of the Connecticut valley; while the first known of these, *Megadactylus polyzelus* from Springfield, Massachusetts, v. Huene (1906, pp. 115-118) refers to the genus *Thecodontosaurus* itself. *Tanystrophæus*, ancestral to the delicate, hollow-boned *Cœluridæ*, begins also in the Muschelkalk, and while differing widely from *Thecodontosaurus*, its successor *Cœlophysis*, from beds in Colorado equivalent to the Upper Keuper of Europe, converges again toward the Thecodontoid phylum, so that the later representatives, *Cœlurus* on the one hand and the Compsognathoid forms on the other, are closely approximated.

In the Lower Keuper a new genus, *Zanclodon*, appears in Europe, of greater size than its contemporaries, and from which v. Huene (1909, p. 20) would derive *Ceratosaurus* of the Morrison with no annectant forms. There are, however, among the Connecticut valley footprints (Rhætic), besides numerous ones referable to the Thecodontoid types (*Anchisauripus* Lull—1904, p. 468), those of a large carnivore with powerful anterior claws but with a relatively feeble hallux. This track which Hitchcock called *Gigandipus* (Lull, loc. cit., p. 492) because of its great size, may well have been made by a member of the *Zanclodon* phylum, the bones of which are as yet unknown in these deposits.

The Middle Keuper ushers in another genus in the form of *Teratosaurus*; giving rise, in the Rhætic, according to v. Huene, to two main branches, from one of which arose, through *Gressylosaurus* and *Euskelosaurus*, the great Megalosaurian line, the other giving rise, through *Plateosaurus*, to the Sauropoda. This seems to me, however, to place the divergence of the Sauropoda somewhat too late in time; to the implied phylogeny I take no exception.

The Connecticut valley forms, which had reached great profusion, to judge from the abundance and variety of their footprints, are contemporaneous with the European Rhætic. Footprints apparently of equivalent age and character are found in New Mexico as well.

The lower Keuper beds contain *Thecodontosaurus* and possibly *Massospondylus* in India (Lydekker 1890, p. 22), while the Upper Keuper entombed the former genus in Australia.

The Upper Karoo beds of Africa, referred by v. Huene to the Rhætic and by Broom (1907, p. 161) to the Lower Jura (Stormberg Beds), contain *Thecodontosaurus*, *Euskelosaurus* and *Massospondylus*, all Triassic types.

*Jurassic.*

During Jurassic time the record is confined practically to England and the adjacent parts of France until the ushering in of the North American Morrison and Potomac toward its close.

While several species of carnivores are found in England and France during this period, they are all referred to the genus *Megalosaurus* with the exception of the Kimmeridgian *Streptospondylus* of England and *Compsognathus* of equivalent age from the lithographic limestone of Solenhofen, Bavaria.

Dr. A. Smith Woodward (1906, pp. 1-3) has recently described a Megalosaurian ungual phalanx from the Lower Jurassic of Victoria, Australia. He does not, however, suggest a more precise correlation of the beds with those of Europe.

*Lower Cretaceous.*

The American Morrison in the West and the basal Potomac (Patuxent-Arundel) in the East have yielded a number of Theropoda; from the Potomac, *Allosaurus*, the American representative of *Megalosaurus* and *Celurus*; while the Morrison has produced, in addition to these forms, *Creosaurus* and *Labrosaurus*, the horned carnivore *Ceratosaurus*, and the agile "bird-catching" dinosaur *Ornitholestes*.

In Europe the Wealden, probable equivalent in part to the American Morrison, has produced numerous remains of *Megalosaurus*. This genus is also reported from the Albion or Gault of France and from the Bellasien of Portugal, considered by Chaffat to be midway between the Aptian and Cenomanian.

*Upper Cretaceous.*

In the Upper Cretaceous, ushered in by the Cenomanian, the European species of Theropoda are, almost without exception, referred to the genus *Megalosaurus*, a well-nigh incredible range, Lias to Danian, for a single genus, even of a relatively conservative type. Depéret (1899, p. 692) has referred a carnivore from the Danian (Rognac) of Montagne-Noire, France, to the genus *Dryptosaurus*, first made known from the Upper Cretaceous of New Jersey.

The New World carnivores, on the other hand, have been given various names; of these the principal types are *Dryptosaurus* of the New Jersey Greensand and the Judith River (Senonian) of Montana and Alberta and *Tyrannosaurus* of the Laramie (Danian) among the huge Megalosaurus; while the lesser race is represented by *Ornithomimus* of the Judith River beds, a probable derivative from *Ornitholestes* of the

Morrison. From the Guaranitic beds (Danian) of Patagonia two genera of carnivores, *Genyodectes* (Woodward 1901) and *Loncosaurus* (Ameghino 1900, p. 61), both similar to *Megalosaurus*, have been described.

#### *The Sauropoda.*

The oldest undoubted Sauropod dinosaur thus far recorded is *Dystrophæus*, described by Cope (1877), from the Red beds of the Painted Canyon in southeast Utah, which he refers to the Trias, but which v. Huene (1904, pp. 320-321), upon the evidence offered by Whitman Cross, believes to be the equivalent to the Dogger. Doubtless owing to the dearth of Jurassic continental deposits, the American record is a blank from this time until the Morrison and its equivalent, the Lower Potomac of Maryland. Sauropoda appear in England with the Bathonian (Great Oölite) in the form of the generalized *Cetiosaurus*.

The Oxfordian has produced *Ornithopsis*, the Kimmeridgian *Ornithopsis*, *Bothriospondylus* and *Pelorosaurus*; the Portlandian, the first of these; while in the Lower Cretaceous Wealden we find *Cetiosaurus*, *Pelorosaurus*, *Morosaurus* and *Titanosaurus* (Lydekker non Marsh). *Cetiosaurus* and *Pelorosaurus*, v. Huene believes, represent parallel phyla giving rise, in the first instance, to the aberrant American *Brachiosaurus* and *Haplocanthosaurus* of the Morrison, while *Pelorosaurus*, through an early *Morosaurus* as a central type, gives rise to *Atlantosaurus* and *Apatosaurus* (*Brontosaurus*) on the one hand, and *Diplodocus* on the other, being succeeded in time by *Titanosaurus* (Lydekker) which ranges as high as the uppermost Cretaceous.

The American basal Potomac beds have produced *Pleurocælus*, which is also found in the Wealden of England and Purbeckian of France. The Trinity sands of Texas, of probable equivalent age to the upper Aptian, contain the remains of *Morosaurus*, a typical Morrison genus.

In the southern hemisphere, in Africa, Madagascar and India, in beds of an age approximately equivalent to the Cenomanian, there have been found *Titanosaurus* and allied genera, such as *Gigantosaurus*, *Bothriospondylus* and, in Patagonia in the Guaranitic beds, *Titanosaurus*, *Argyrosaurus* and the relatively small aberrant *Microsaurus*.

Depéret (1889, p. 692) has also described *Titanosaurus* from the Rognac, Danian, of Saint Chinian in the south of France, the last record of the Sauropoda in Europe.

#### *Orthopoda—Ornithopoda.*

The Ornithopod dinosaurs, which exclude the armored types, make their first appearance in the North American

Upper Triassic, the possible equivalent of the Rhætic, being represented in the bone by *Nanosaurus*, of the Hallopus beds near Cañon City, Colorado, described by Marsh as a carnivore, but which v. Huene and Lull (1908, p. 143) have lately referred to this order. This type comes from the Upper Trias or Lower Jura of Colorado and is absolutely unique.

Williston, in a letter to the author dated Cañon City, Colorado, July 11, 1909, says: "After a careful study of the locality and region the conclusions I reach are: Nothing more definite as to the age of the Hallopus beds can be said than was given by Marsh. In my opinion they are either uppermost Trias or Lower Jurassic, though possibly of Middle Jurassic age. No fossils of any kind have ever been found below them in the Cañon City region. The type [of *Hallopus*] was found between 60 and 70 feet above the Red beds, doubtless of Triassic age. The intervening strata are distinctly conformable with the Red beds. All the known Morrison fossils from Cañon City are from above the Hallopus horizon, from one to three hundred feet, though numerous fragments of sauropods in the hillside suggest the possibility of less interval between them. There is no persistent red sandstone stratum in the Hallopus horizon. \* \* \* my conclusion is that, until other fossils are found to fix more definitely their age, it is unwise to assign definitely either Triassic or Jurassic age to them. Jura-Trias will express this uncertainty."

Impressed upon the rocks of the Newark system, the equivalent of the Old World Rhætic, in the Connecticut valley and New Jersey are numerous footprints which Lull (1904, p. 499) has shown to pertain to ornithopod forms, the genus *Anomæpus* unquestionably. Two other genera may also belong to the Ornithopoda, *Eubrontes* of larger size and the aberrant *Otozoum*, the bipedal tracks of which indicate a foot unlike that of any known dinosaur. The footprints included under the genus *Anomæpus* show a considerable range in size but are all such as could have been made by forms like *Nanosaurus* and *Hypsilophodon*.

England again gives us the only record of Jurassic types, if we eliminate *Nanosaurus* and the Morrison forms, *Camptosaurus prestwichii* described as *Iguanodon* being found in the Kimmeridge clay. The other Jurassic types which have been referred to *Camptosaurus* Gilmore (1909, pp. 289-292) considers as invalid so far as the genus is concerned. The Oxfordian has yielded *Cryptodraco* (*Cryptosaurus*) which v. Huene (1909, p. 21) considers as ancestral to *Camptosaurus*, the central type of this group.

From the American Morrison are *Camptosaurus*, and a lesser form *Laosaurus* and its relative *Dryosaurus*, which, together



with the persistently primitive Wealden *Hypsilophodon*, v. Huene derives from the Colorado *Nanosaurus*. Lull (1910) will report *Dryosaurus* also from the basal Potomac beds of Maryland, and Gilmore (1909, pp. 392-395) has described a *Camptosaurus* from the Lakota in South Dakota.

The Wealden of England and especially of Belgium has yielded remarkably preserved specimens of *Iguanodon*, the successor of *Camptosaurus*. *Iguanodon* is in turn succeeded in the Cenomanian of England by a type referred to the American genus *Trachodon*, but somewhat questionably.

In America, the Niobrara, the equivalent of the European Turonian, has yielded the type of *Claosaurus agilis*, which is followed in the New Jersey Greensand and in probably equivalent beds of North Carolina by *Trachodon* (*Hadrosaurus*).

In the West, *Trachodon* is found in the Judith River beds and again in the Laramie, where it lingers on until the final extinction of the dinosaurian race at the close of the Mesozoic.

The European Cenomanian has produced *Craspedodon* in Belgium and *Mochlodon* from the Gosau formations of Austria. *Rhabdodon*, found in Rognac of southern France and in the Mæstricht beds of Belgium and Holland, both of the Danian period, is probably the closing member of the race in Europe.

#### *Armored Orthopoda—Stegosauria.*

The Stegosaurians have their first known representative in *Scelidosaurus* of the English Lias, beyond which the record is blank until we come to *Dacentrus* (*Omosaurus*) of the Kimmeridgian, which appears to be the central type in the evolution of this group. The Morrison yields *Stegosaurus*, which some authors have identified with the European *Dacentrus*, but which appears to be an aberrant side branch derived also from the Scelidosaurian stem. In the basal Potomac beds of Maryland several teeth and more questionably a vertebra (Lull 1910) are described as *Priconodon* and referred to the Stegosauria.

The Purbeckian of England has also yielded *Priconodon*, while from the Wealden come *Polacanthus* and *Hyalosaurus*, the latter being found in Belgium as well as in England. *Acanthopholis*, from the English Cenomanian, v. Huene makes the connecting link with *Ankylosaurus* of the Laramie.

Intervening forms in the series, however, are probably represented by *Nodosaurus* from the Pierre (Turonian) of Colorado, while *Stegopelta*, recently described by Williston (1905, pp. 503-505) from the Lower Benton of Wyoming, and *Palaeoscincus* of the Judith River are closely related if not identical

with *Ankylosaurus* of the Laramie. All three, according to Williston, were derived from *Polacanthus* of the Wealden of Europe.

The Gosau beds of Wiener Neustedt near Vienna, probably equivalent to our Judith River, contain a number of armored forms such as *Struthiosaurus* (Nopcsa 1902) and *Acanthopholis* (Nopcsa 1902) some of which, at least, probably pertain to the same race.

### *Ceratopsia.*

The Ceratopsia have a relatively brief career,—*Stenopelix*, the pelvis of which resembles that of *Triceratops*, being the earliest possible representative among known forms. It is found in the Neocomian of Germany. The remains described by Seeley (1881, pl. xxviii, fig. 4) from the Gosau formation under the name of *Cratæomus* (= *Struthiosaurus*; Nopcsa 1902) contain what appears to be a ceratopsian left supra-orbital horn-core which would seem to represent a stage of evolution equivalent to *Ceratops* of the American Judith River. Nopcsa (1902, p. 7) is of the opinion, however, that the horn-like bone in question represents a dorsal spine after the manner of those of *Polacanthus*. This, together with the total absence of two-rooted teeth of the ceratopsian sort among the number preserved at Vienna, casts grave doubt upon the existence in Europe of this remarkable group.

The American Judith River (= Belly River of Canada) contains two stages in the evolution of the Ceratopsia, *Monoclonius* and *Ceratops*, as well as the somewhat aberrant *Centrosaurus* described by Lambe (1904). The Laramie deposits which follow later after a hiatus of some 2,000 or more feet of marine strata contain the terminal members of this race, *Triceratops* and *Torosaurus*. The geological distribution and phylogenies are shown in figure 1.

## V. GEOGRAPHICAL DISTRIBUTION.

### *Theropoda.*

The geographical distribution of dinosaurs presents some very interesting problems, some of which, at first sight, are difficult to explain.

By far the widest spread forms are the carnivorous Theropoda (fig. 2), evidently the most adaptable and of a nature not so subservient to a peculiar kind of food, which was apt to be local in distribution, as in the case of the plant-feeding forms. These carnivores are reported in practically every locality where herbivorous dinosaurs have been found, as they seem to



have accompanied the latter in all of their wanderings. In addition to this they had, during Triassic times, deployed rapidly before our records give us evidence of the existence of the herbivores.

The oldest recorded Theropoda, those of the Lower Muschelkalk, are found in Germany, but we have no proof that this was the center of dispersal. Indeed v. Huene (1908, pp. 100-101) is of the opinion that one must go farther west, where a great continent extended from England to America, to find the conditions which, we have imagined, must have given rise to the dinosaurian race. During the Keuper, particularly, "a brackish sea and swamp extended from England to Eastern Germany as far as the Scandinavian, East Prussian and Bohemian borders, where another great northern continent began and extended eastward."

The semi-arid continent of Triassic time would doubtless be the chosen habitat, the swamp regions the place where the remains of wandering individuals might more readily be preserved.

During the Trias. the Theropoda spread in one direction through Germany, France, England, and in the other to eastern and finally to western North America, which was reached not later than the Upper Keuper. On the other hand, they migrated southward in the Old World to the Gondwana continent, for in the Lettenkohle time we find them in India, in the Upper Keuper in Australia, while South Africa was reached at least by Rhætic time.

What the precise line of march was is somewhat doubtful—I imagine, however, it was southward to what is now northern Africa, thence east to India and Australia, and south to the Cape Colony. We have no recorded evidence of Triassic dinosaurs in South America or in New Zealand. I should hesitate to infer that they had not reached South America during this period, though, as we shall see, the first remains to be found are not older than the Wealden. New Zealand, however, has yielded a rich Triassic flora, together with the remains of labyrinthodonts, implying extensive terrestrial deposits though not the ideal dinosaurian habitat; but as Theropoda are found in all sorts of deposits, even marine, that feature is not especially significant. The total absence of the dinosaurs from New Zealand deposits of any age; the presence in the Permian and Trias of labyrinthodonts; the presence to-day of the absolutely unique *Hatteria*, the sole survivor of its order, dating its ancestry also from the Permian; the presence of no tailed amphibia, of one rare species of frog, of a few lizards, which Heilprin tells us cannot pass the sea as adults, but do in the egg as they are found on remote oceanic islands to which they

FIG. 2.

Lower Muschel- kalk	Upper Muschel- kalk	Letten- kohle	Lower Keuper	Middle Keuper	Upper Keuper	Rhaetic
				NORTH AMERICA		<i>Amosaurus</i> , Manchester, Conn. <i>Anchisaurus</i> " " <i>Thecodontosaurus</i> , Springfield, Mass. <i>Coelophysis</i> , Gallinas Mountains, N.M.
				ENGLAND		<i>Grasyllosaurus</i> , Wedmore Hill, Somersetshire. <i>Platysaurus</i> , Brigend, Glamor- ganshire. <i>Platysaurus</i> , Leicester. <i>Thecodontosaurus</i> , Warwick; Durdham Down; Bristol.
				FRANCE		<i>Platysaurus</i> , Provenchère, Hte. Marne; Buerre and Domblans n. Besançon; Bois de Chassagne, Poliigny, Jura; Pèchaux n. Lons-le-Saunier. <i>Grasyllosaurus</i> , Provenchère, Hte. Marne; Bois de Chassagne, Poliigny, Jura; Lons-le-Saunier
				GERMANY		<i>Platysaurus</i> , n. Göttingen, n. Hedeper Schlosslessmühle in Sohlbühch, n. Tübingen. <i>Platysaurus</i> , n. Katzenhof, Pegnitzthal, Unterfranken, n. Murenberg, n. Bayreuth, n. Tübingen, n. Stuttgart, Balingen. <i>Grasyllosaurus</i> , n. Murenberg, n. Tübingen, n. Stuttgart. <i>Pachysaurus</i> , n. Tübingen, n. Rottweil, n. Gmünd, n. Löwenstein. <i>Taratorius</i> , n. Rottweil, n. Stuttgart, n. Brack- enheim, n. Murenberg. <i>Sellosaurus</i> , n. Stuttgart, n. Brackenheim. <i>Tanyatrophus</i> , n. Stuttgart. <i>Thecodontosaurus</i> , n. Stuttgart. <i>Zanclodon</i> , n. Ludwigsburg, n. Stuttgart, n. Hall. <i>Thecodontosaurus</i> , Bayreuth, n. Crailsheim. <i>Tanyatrophus</i> , Bayreuth, n. Crailsheim, Hall, Oberbronn, Alsatia. <i>Thecodontosaurus</i> , Gogolin, Upper Silesia. <i>Tanyatrophus</i> , Gogolin, Krappitz.
				SWITZERLAND		<i>Grasyllosaurus</i> , n. Basel
				SOUTH AFRICA		<i>Thecodontosaurus</i> , Barkley-East (Stormberg beds), Aliwal North. <i>Euskelosaurus</i> , Aliwal North. <i>Massospondylus</i> , n. Harri Smith, Drakenberg.
				INDIA		<i>Thecodontosaurus</i> , ? Ranigansoh.
				AUSTRALIA		<i>Thecodontosaurus</i> , North-east Coast.

FIGURE 2. Distribution of the Triassic Theropoda (adapted from v. Huene).

**FIG. 3.**

Time	Pullonian	Sathonian	Oxfordian	Cpralli-an	Elmerid-gian	Portlan-dian	Partheekian
				MEGALOPODA			
				ENGLAND			<u>Nathates</u> , Swanage, Dorset.
					<u>Megalosaurus</u>		
					<u>Megalosaurus</u> , Wiltshire.		
					<u>Megalosaurus</u> , Yorkshire.		
					<u>Megalosaurus</u> , Weymouth.		
					<u>Megalosaurus</u> , Stonesfield, Enslow, Oxford.		
					<u>Megalosaurus</u> , Bridport, S.W. England.		
<u>Megalosaurus</u> , Lyme Regis.							
				GERMANY			
					<u>Compsognathus</u> , Solenhofen, Bavaria.		
				FRANCE			
					<u>Megalosaurus</u> , Boulogne-sur-Mer.		
					<u>Megalosaurus</u> ( <u>Streptospondylus</u> ), Le Havre, Devises, Boulogne, Cape-de-la-Neve.		
					<u>Megalosaurus</u> , Calvados.		
					<u>Megalosaurus</u> , Caen in Calvados, Saint-Gauthier.		
<u>Megalosaurus</u> , Franche-Comte.							
				SPAIN			
<u>Megalosaurus</u> , Buedes (Asturias).							
				PORTUGAL			
					<u>Megalosaurus</u> , Mont Lambert.		
					<u>Megalosaurus</u> (Lucitanien), Pombal, environs of Crasto.		
				AUSTRALIA			
					<u>Megalosaurus</u> , Cape Patterson, Victoria (precise horizon doubtful)		
				SAUROPODA			
				NORTH AMERICA			
					<u>Dryptosaurus</u> , Painted Cañon, S.W. Utah.		
				ENGLAND			
					<u>Palorosaurus</u> ( <u>Ornithopsis</u> ), Isle of Portland.		
					<u>Palorosaurus</u> , Stretham, Cambridgehire.		
					<u>Palorosaurus</u> ( <u>Rothriospondylus</u> ), Swindon, Bradford, Wiltshire.		
					<u>Palorosaurus</u> ( <u>Ornithopsis</u> ), Weymouth, Ely.		
					<u>Palorosaurus</u> , Peterborough.		
					<u>Palorosaurus</u> ( <u>Ornithopsis</u> ), Wyebury, Oxfordshire.		
					<u>Cetiosaurus</u> , Peterborough.		
					<u>Cetiosaurus</u> , Oxford, Stonesfield, Blisworth, Bilbury, Enslow, Cogenhoe.		
				FRANCE			
					<u>Palorosaurus</u> , Boulogne-sur-Mer.		
					<u>Palorosaurus</u> , Wisille n. Eoulogne.		
					<u>Palorosaurus</u> ( <u>Rothriospondylus</u> ), n. Havre.		
					? <u>Palorosaurus</u> (Tooth), Saint-Gauthier		
					<u>Cetiosaurus</u> , Caen.		
				PORTUGAL			
					<u>Palorosaurus</u> , Vestaria.		
					<u>Palorosaurus</u> , Ouren.		
				MADAGASCAR.			
					<u>Palorosaurus</u> (Dogger)		

**Fig. 3. Distribution of the Jurassic Theropoda and Sauropoda (original).**

may have found means of introduction by floating timber; the absence of any indigenous mammals other than bats, a rat, and the Maori dog, the introduction of which may be as readily accounted for;—all of these evidences seem to me to point to an utter isolation geographically on the part of New Zealand since the close of the Permian. De Lapparent's maps (1906) indicate a continuous New Zealand-Australian connection into the basal Eocene—long after the breaking up of the Gondwana continent. The biological evidence which I have given strongly opposes this view.

During Jurassic times the record of Theropoda (fig. 3) is practically continuous in England and Europe, and one Megalosaur has been described by Smith Woodward (1906) from the Lower Jurassic of Cape Patterson, Victoria, Australia, about the nearest point toward the unattainable New Zealand.

For Africa, South America, and most strikingly for North America, the known Theropod record is a perfect blank throughout the Jurassic, though the remains of other dinosaurs are sparingly known. This is unquestionably due to dearth of known terrestrial deposits in Africa and North America, for the few which exist have thus far yielded no dinosaur remains. As for South America, it may be that the migrant dinosaurs did not arrive until the beginning of Lower Cretaceous time.

The Lower Cretaceous (fig. 4) saw the Theropoda at their widest extent, the Wealden of England and the Morrison and basal Potomac of North America having yielded a marvelous assemblage of types. In Europe their record is seen somewhat scatteringly throughout the Lower and Upper Cretaceous, indicating that they inhabited the whole area throughout the period. In North America, while there are extensive breaks in the continuity of the record, the great numbers and wide distribution at the beginning and end imply an equally extensive distribution in time and space. Central Africa, near the Tchad See, yields theropod remains during the Cenomanian; Madagascar, India and Australia as well in beds of approximately equivalent age; while in the neighborhood of Bahia, Brazil, in beds of an age equivalent to the Wealden, is found the first positive indication that these forms had reached South America. Having once found a foothold in South America, the Theropoda lingered on until the close of the Cretaceous, as their remains are reported from several localities in Patagonia in the Guaranitic (Danian) strata.

#### *Sauropoda.*

The Sauropoda (fig. 5) are also very widespread though evidently local in distribution owing to necessary peculiarities in habitat and food. Their appearance in time is startling, as

FIG. 4.

Seiden Morrison	Aptian	Albian	Cenomanian	Turonian	Santonian	Danian
			NORTH AMERICA			<p><i>Tyrannosaurus</i>, Hell Creek, Mont.; E. Fork of Little Powder R., Mont.; Ojo Alamo, N.M.; Converse Co., Wyo.</p> <p><i>Ornithomimus</i>, Converse Co., Wyo.; n. Denver, Col.</p> <p><i>Ornithomimus</i>, Red Deer River, Alberta, Can.; Mont.</p> <p><i>Ablyndonos</i>, Judith, Mont.; Red Deer River, Alberta.</p> <p><i>Dainodon</i>, Judith, Mont.; Red Deer River, Alberta.</p> <p><i>Dryptosaurus</i>, Red Deer River, Alberta; Haddonfield, N.J.</p> <p><i>Coelocerosaurus</i>, Haddonfield, N.J.</p> <p>?<i>Allosaurus</i>, Kansas.</p>
<i>Allosaurus</i> , Como, Wyo.; Bone Cabin n. Medicine Bow, Wyo.; Canyon City, Col.; Prince George Co., Md. (Potomac).						
<i>Machrosaurus</i> , Como, Wyo.; Canyon City, Col.						
<i>Troosaurus</i> , Como, Wyo.						
<i>Ceratosauros</i> , Como, Wyo.; Canyon City, Col.						
<i>Ornitholestes</i> , Bone Cabin, Wyo.						
<i>Coelurus</i> , Como, Wyo.; Prince George Co., Md.						
			ENGLAND			
<i>Megalosaurus</i> , Hastings, Cuckfield, Isle of Wight.						
<i>Calamospondylus</i> , Isle of Wight.						
<i>Coelurus</i> , Isle of Wight.						
			FRANCE			<i>Dryptosaurus</i> , Saint Chinian.
<i>Megalosaurus</i> , Boulonnais, Grand Pré, Louppy.						
			PORTUGAL			<i>Megalosaurus</i> , Viseu.
<i>Megalosaurus</i> , Boco do Chapin, Cap d'Espichel.						
			BELGIUM and HOLLAND			<i>Megalosaurus</i> , Maastricht.
					<i>Megalosaurus</i>	
<i>Megalosaurus</i> , North Germany.			GERMANY			
			AUSTRIA and HUNGARY			<i>Megalosaurus</i> , n. Vienna (Neue Welt) Siebenbürgen.
			AFRICA			
			"Ornithomimus-like", Tobad-See, Centre Africa.			
			MADAGASCAR			<i>Megalosaurus</i>
			<i>Megalosaurus</i> , Nevarane.			
			INDIA			
			<i>Megalosaurus</i> , Trichinopoly.			
			AUSTRALIA			
			<i>Megalosaurus</i> , New South Wales (Geol. level not given)			
			SOUTH AMERICA			<i>Loncosaurus</i> , Rio Rehue, Patagonia.
<i>Megalosaurus</i> , Bahia, Brazil.						<i>Rapinodactylus</i> , Patagonia.

FIG. 4. Distribution of the Cretaceous Theropoda (original).



they are found in strata which v. Hueue refers in each case to the Dogger but at points far removed geographically, in England, in Utah, and in Madagascar (v. Huene, 1909, p. 14). If v. Huene is correct in his derivation of the group from the Theropod genus *Plateosaurus*, I should look to this swamp-land extending during the late Trias from England to Eastern Germany, before alluded to (vide supra p. 21) as the place of origin of the race. That they reached such remote places before their very existence is indicated in our records points to the incompleteness of the latter and good powers of migration along the swamp and delta formations which fringed the continental shores.

The Sauropoda are abundant in England from the Bathonian (Dogger) to the Wealden, in France from the Bathonian until the Aptian, and then, if Depéret (1899) is right, after a lapse of time during which no Sauropoda left their records elsewhere in the northern hemisphere, they appear again in the form of *Titanosaurus* at Saint Chinian and Languedoc in southern France in beds referable to the Danian—the very close of the Cretaceous period!

In America, with the exception of *Dystrophæus* of the Dogger of Utah and an unnamed Sauropod reported by Gilmore (1909, p. 300) from the Lakota (Aptian) of Buffalo Gap, South Dakota, the Sauropoda are confined entirely to the Morrison and its eastern equivalent, the basal Potomac, and in the South, to the Trinity sandstones of Texas and Oklahoma. A remarkable feature of the career of the American types is that, with the exception of the ill-known *Dystrophæus*, the most generalized *Haplocanthosaurus* and the most specialized *Diplodocus* have been found associated in the same quarry, although Riggs (1904, p. 246) argues for *Haplocanthosaurus* a terrestrial habitat, on account of the similarity in length of fore and hind limb and the apparent inflexibility of the vertebral column; while *Diplodocus* shows the highest degree of aquatic adaptation known within the group.

In the southern hemisphere one finds sauropod remains from India across Madagascar and East Africa to Patagonia, almost the entire length from East to West around the south shore of the old Gondwana continent. There is, however, no record of their occurrence in Australia, a piece of negative evidence which can hardly be weighed heavily in view of the meagerness of the known dinosaur remains in that quarter of our globe.

The principal southern genus is *Titanosaurus* (Lydekker non Marsh), the remains of which are found also in the English Wealden. The beds wherein the southern Sauropods are found are, curiously enough, Upper Cretaceous, probably

FIG. 5.

Valdean	Aptian	Albian	Cenomanian	Turonian	Santonian	Danian
Morrison			aa			
NORTH AMERICA						
Atlantosaurus, Canyon City, Col.; Morrison, Col.						
Anteosaurus (Brontosaurus), Como, Wyo.; Bone Cabin, Wyo.; Medicine Bow, Wyo.; Sheep Creek, Wyo.; Grand River Valley n. Fruita, Col.; Freese Out Hills, Wyo.; Morrison, Col.; Webster Park, Col.						
Morrison, Oklahoma (Trinity Sands).						
Morrison, Como, Wyo.; Canyon City, Col.; Grand River Valley, Col.; Freese Out Hills, Wyo.						
Carrerasaurus, Canyon City, Col.						
Pleurocoelus, Prince George Co., Md. (Potomac); Como, Wyo.						
Diplodocus, Bone Cabin, Wyo.; Sheep Creek, Wyo.; Canyon City, Col.; n. Morrison, Col.						
Barosaurus, Piedmont, S.D.						
Brachiosaurus, Grand River Valley, Col.						
Aplocanthosaurus, Canyon City, Col.						
"Sauropod" (Lakota), Buffalo Gap, S.D.						
ENGLAND						
Cetiosaurus, Isle of Wight; Cuckfield, Sussex.						
Palaeosaurus, Isle of Wight; Sandown, Cuckfield, Sussex.						
Palaeosaurus (Ornithopsis), Cowden.						
Titanosaurus, Isle of Wight.						
Morrison, Cuckfield, Sussex.						
Pleurocoelus, Hastings, Cuckfield, Isle of Wight.						
Morrison, Isle of Wight.						
FRANCE						
Titanosaurus, Saint Chinian, Languedoc.						
Apyrosaurus, Mont Ventoux (Vaucluse) Perigord.						
Pleurocoelus, Caen.						
PORTUGAL						
Pleurocoelus, Boca do Chapin, Cap d'Espichel.						
AFRICA						
Alcosaurus, Port Elizabeth (precise level doubtful).						
Titanosaurus, Tendaguru, East Africa.						
Gigantosaurus, Tendaguru, East Africa.						
MADAGASCAR						
Titanosaurus, Nevarane.						
Palaeosaurus (Bothriospondylus), n. Bay of Marinda.						
INDIA						
Titanosaurus (may be Albian), Maleri, Piedura.						
SOUTH AMERICA						
Titanosaurus, Neuquen, Rio Chahut, Patagonia.						
Apyrosaurus, Rio Chahut, Patagonia.						
Microsaurus, Neuquen, Patagonia.						

FIG. 5. Distribution of the Cretaceous Sauropoda (original).



not older than Cenomanian time, and, with the exception of the questionable *Macrourosaurus* of the English Cenomanian and the *Titanosaurus* reported by Depéret (vide supra) from the Danian of Southern France, the contained dinosaurs represent by far the latest appearance of the Sauropod group anywhere recorded on the face of the globe.

The last stand of these huge creatures, so far as our present knowledge goes, and again excepting Depéret's *Titanosaurus* (vide supra, p. 26), was in Patagonia, where the remains of three genera, *Titanosaurus*, *Argyrosaurus* and the small aberrant *Microsaurus* are found in the Guaranitic beds correlated by Hatcher (1900, p. 95) with the Laramie (Danian) of North America.

### *Orthopoda.*

Geographically the Orthopoda (figs. 6 and 7) as a whole, with the exception of the Ceratopsia, which are apparently confined to western North America, have a common distribution; and, while paralleling that of the other dinosaurs in the northern hemisphere, are unique in their entire absence from the southern. It can hardly be said that the paucity of our records is responsible for this apparent lack of southern forms, for their preservation and discovery should surely have brought some to light when the Theropoda and Sauropoda are relatively so abundant.

America seems to have been the original home of the orthopod dinosaurs, the first recorded type the bones of which are known being *Nanosaurus* of the Jura-Trias of Utah. In the upper series of the Newark (Rhætic) beds in Massachusetts, Connecticut and New Jersey are indications of numerous species of these plant-feeding forms, so that it is evident that by the beginning of Jurassic time not only were they widespread in North America but they had reached a considerable degree of variation as well, implying a long though unrecorded career. During the Jurassic the record is again a blank as with the American Theropoda, but with the ushering in of Lower Cretaceous time by the great Morrison deposits in the West and the Potomac in the East we find a marvelous assemblage of types, small and large, armored and unarmored. This is especially true in the West, since the Potomac dinosaurs, coming as they do from few localities which are all of one character, reflect the Sauropod rather than the Orthopod habitat, so that while an armored dinosaur, *Priconodon*, and an unarmored *Dryosaurus* (Lull 1910) only have been found in Maryland, others doubtless existed and may some day be brought to light.

All through Upper Cretaceous time the American record is quite complete, especially in the West, though New Jersey,

FIG. 7.

Vealden Morrison	Aptian	Albian	Cenomanian	Turonian	Senonian	Danian
			<b>STEGOSAURIA</b>			
			<b>NORTH AMERICA</b>			
						<u>Ankylosaurus</u> , Hell Creek, Mont.
						<u>Ankylosaurus</u> ( <u>Stegoscephalus</u> ), Red Deer River, Alberta.
						<u>Palaeocinacrus</u> , Red Deer River, Alberta; Judith River, Mont.
						<u>Medosaurus</u> , n. Como, Wyo.
						<u>Stegopalis</u> , Lander, Wyo.
						<u>Microrosaurus</u> ( <u>Niobrara</u> ), Gove Co., Kan.
						<u>Hoplitosaurus</u> ( <u>Lakota</u> ), Buffalo Gap, S. D.
						<u>Stegosaurus</u> , Como, n. Medicine Bow, Bone Cabin, Sheep Creek, Wyo.
						<u>Stegosaurus</u> ( <u>Diposodon</u> ), Como, Wyo.
						<u>Prisonodon</u> ( <u>Potosac</u> ), Prince George Co., Md.
			<b>ENGLAND</b>			
						<u>Acanthopholis</u> , Polkstone.
						<u>Acanthopholis</u> , Cambridge.
						<u>Polacanthus</u> , Hastings, Isle of Wight.
						<u>Hyalosaurus</u> , Hastings, Tilgate, Cuckfield.
						<u>Ventisaurus</u> , Isle of Wight.
			<b>FRANCE</b>			
						<u>Struthiosaurus</u> ( <u>Cratogeomys</u> ) St. Chinian.
						<u>Hyalosaurus</u> , Boulonnais, Grand Pré.
			<b>GERMANY</b>			
						<u>Hyalosaurus</u> , North Germany.
						<u>Stegopalis</u> , Brückeburg.
			<b>AUSTRIA-HUNGARY</b>			
						<u>Struthiosaurus</u> , n. Vienna (Neue Welt).
						<u>Hoplosaurus</u> , n. Vienna (Neue Welt).
			<b>CERATOPSIA</b>			
			<b>NORTH AMERICA</b>			
						<u>Triceratops</u> , Converse Co., N. Platte River opposite mouth of Medicine Bow, Wyo.; Hell Creek, Powder River, Chalk Buttes 20 mi. N. of Elk Lake, E. Fork Little Powder River, n. Glendive, n. Rosebud, Mont.; Yale, Billings Co., N. D.; Ojo Alamo, N. M.; n. Denver, Col.
						<u>Diceratops</u> , Converse Co., Wyo.
						<u>Torosaurus</u> , Converse Co., Wyo.
						<u>Agathaumas</u> , Black Buttes, Wyo.
						<u>Ceratops</u> (Judith River), n. Judith, Missouri River, Mont.; Red Deer River, Alberta.
						<u>Monoclonius</u> (Judith River), n. Judith, Mont.; Red Deer River, Alberta.
						<u>Centrosaurus</u> (Judith River), Red Deer River, Alberta.
						"Ceratopsians", Musselshell River Basin, Sweet Grass Co., Mont.

FIG. 7. Distribution of the Cretaceous Stegosauria and Ceratopsia (original).

North Carolina and Georgia have yielded Trachodons of Magothy (Senonian) age.

The great culmination of the group, in which the older types were joined by the remarkable Ceratopsia, occurred toward the close of the Cretaceous in the area lying just eastward of the Rocky Mountains and extending from New Mexico on the south to Alberta on the north, perhaps beyond.

In the Old World I have searched in vain for traces of Orthopoda before the Lias. Beasley, Sollas and others have described many fossil footprints from beds ranging from the Bunter to the Upper Keuper, including some undoubted dinosaurian tracks (Sollas 1879, pp. 511-516) resembling those of *Anchisauripus* (*Brontozoum*, part) (Lull 1904, p. 486) of the Connecticut formation. There is none among them in any way comparable with *Anomæpus* (Lull 1904, p. 500) of the New World. Beasley (1907, p. 167-168) is inclined to think that he has in *Chirotherium storetonense* from near Liverpool the footprint of an herbivore. That one may readily consent to, but the foot in no way resembles that of a dinosaur and the tracks are generally referred to unknown labyrinthodonts.

In the English Lias the first Orthopod appears in the form of the armored *Scelidosaurus* followed in the Oxfordian by *Omosaurus* and later by *Echinodon*. Recorded specimens of armored forms are entirely confined to England during Jurassic time and not until the Wealden do we find their remains on the continent. With the Cenomanian they apparently forsake their earlier home entirely for the continent, culminating in *Struthiosaurus* and *Hoplosaurus* of Austro-Hungary and southern France.

The unarmored Orthopoda, the Ornithopoda, begin their Old World career simultaneously in England and Portugal in beds of Oxfordian age, but are not numerous during the Jurassic. The Wealden, however, brings in a great many species, some in wonderful preservation. Their subsequent history is much like that of the armored types, culminating in Austro-Hungary, France and Belgium.

It will be observed that no mention is made of the Asian continent north of India—the ancient Angara-land. Thus far our records show absolutely no trace of dinosaurian remains from any part of this vast area. Professor Marsh (1897, pp. 413-414) says: "In St Petersburg I hoped to find many dinosaurian remains, as here had been brought together an abundance of fossil treasures from various parts of the Russian Empire, which I knew must contain many forms of this group. In the four principal museums of the city, however, I could find no bones of Dinosaurs on exhibition, nor could I learn from any of the museum authorities that such remains had

FIG. 8.

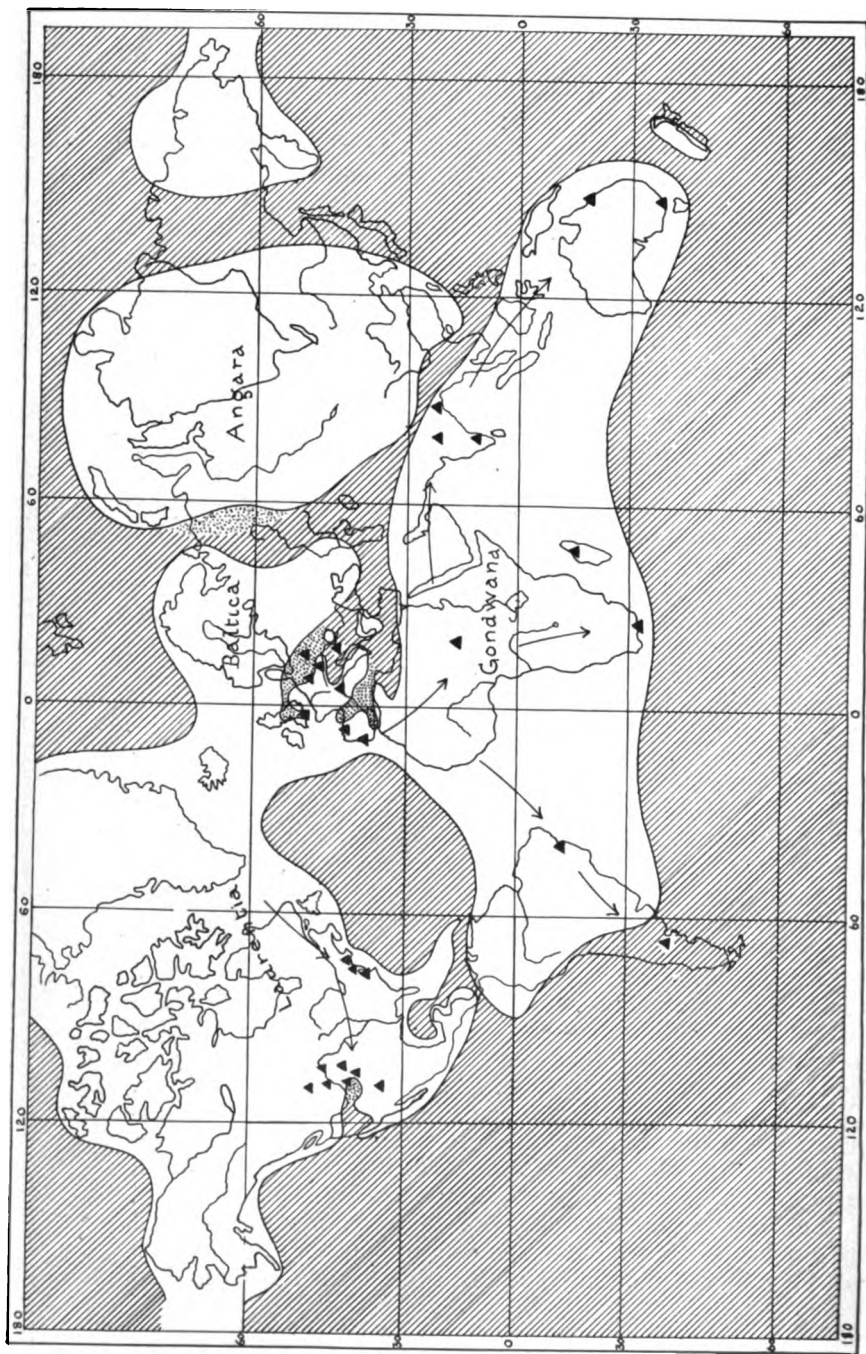


FIG. 8. Map showing the principal localities of the Theropoda with probable routes of migration. Based upon the lower Triassic maps of Schuchert for North America and de Lapparent for the rest of the world. (Dotted areas, terrestrial deposits.)

FIG. 9.

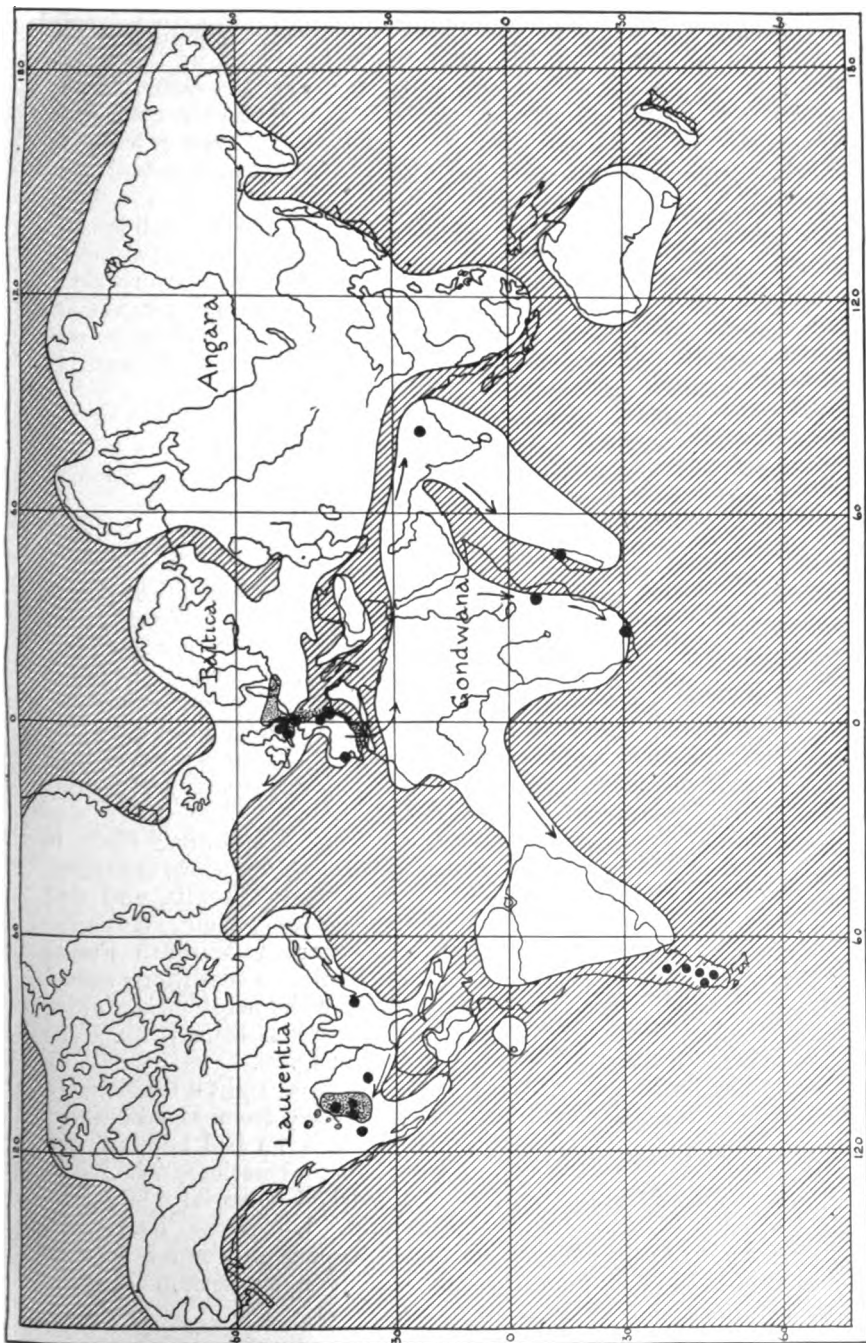


FIG. 9. Map showing the chief localities and probable routes of migration of the Sauropoda. Based upon Schuchert's late upper Jurassic map of North America and de Lapparent's Wealden map for the rest of the world.



been recognized among the specimens received, neither could I find any such fossils myself among the debris of the collections, so often a rich repository for new or inconspicuous specimens. This was true, also, of the smaller collections visited, and I was at last forced to admit that here, at least, the Dinosaurs of Russia like the snakes of Ireland, were conspicuous only by their absence.

"This opinion was not changed by a visit to the rich geological collections of Moscow, which I examined with care; although other fossil vertebrates, including many reptiles, were abundantly represented. I was assured, moreover, by various Russian paleontologists, that in other museums of the empire or in the known localities they had seen no dinosaurian remains."

This evidence can be interpreted again in the light of the fact that Asia is so largely a *terra incognita* from the paleontologist's point of view, or in that of the physical isolation of Angara during the whole dinosaurian epoch.

#### VI. SUMMARY OF MIGRATIONS AND PALEOGEOGRAPHY.

The probable center of evolution and course of migration of the Theropoda has already been sketched. Having their origin apparently somewhere in the northern continent of Laurentia, they deployed southward and westward, covering not only the confines of western Europe but extending into Gondwana, the southern land mass, during Triassic times. New Zealand they never reached and they may have been retarded in their passage to South America until the beginning of the Lower Cretaceous (see fig. 8). The Sauropoda probably had their origin in Europe, migrating early in Jurassic time to the southern as well as to the western continent. Thence in the southern hemisphere both east, south, and west until their range was almost as great as that of their carnivorous allies. Whether the Danian Titanosaur of southern France was a returned migrant or whether suitable conditions caused it to linger long after the death of all of its neighboring allies, like the Steller's sea cow in Behring Sea, I cannot say. The second idea seems the more probable (fig. 9).

The Orthopoda (fig. 10) present at first sight a much more serious difficulty in their entire absence from the southern hemisphere. It would seem as though we had here a group the center of whose dispersal was North America. They were truly terrestrial types, many of marked cursorial adaptation, which should be as capable of migration as the Theropoda. They were, however, dependent upon a peculiar sort of food which was in turn dependent upon certain climatic

FIG. 10.

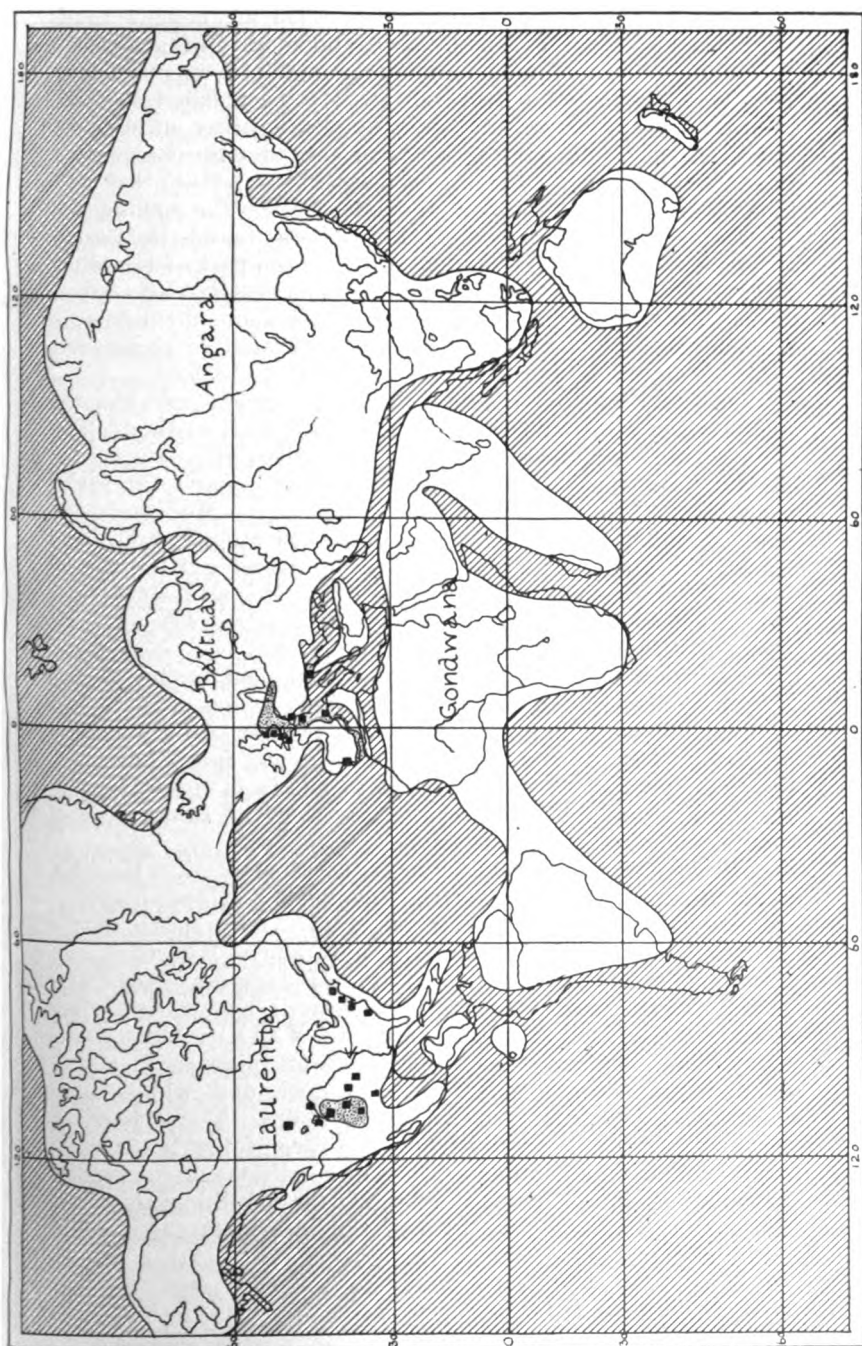


FIG. 10. The same map as in fig. 9, showing localities and migratory routes of the Orthopoda.

conditions and necessarily went where food was abundant and were checked where it failed. The opportunity for migration to Gondwana Land from Europe by a dry land route may readily have ceased before the Orthopoda reached the Old World. The Sauropoda, on the other hand, being amphibious could cross broken land connections provided the water were not of too great an extent. It is a significant feature that only Theropods, Sauropods and the late Cretaceous Orthopods, *Claosaurus* and *Trachodon*, have been found in marine deposits, indicating a semi-aquatic life on the part of the latter two and at least a fearlessness of water when necessity arose upon that of the carnivores. By the time the Trachodont dinosaurs reached the Old World the opportunity for southern migration even for an amphibious animal had apparently ceased.

A comparison may well be made with living mammals, the deer on the one hand, the hippopotamus on the other. The former are world-wide in their distribution except for Australasia, the Arabian peninsula and Africa, save for a single species, *Cervus barbarus*, which inhabits the Mediterranean coast from Tunis to the slopes of the Atlas range. Schillings (1906, p. 261) says: "In 1896 hippopotamuses were still plentiful in the Nzoia River and the Athi River in British East Africa; they were to be found, too, along the coast between Dar-es-Salaam and Pangani. I saw them on several occasions in the surf, and I shall never forget my astonishment once, on getting out of a clump of cocoanut palms, to see what I had imagined to be an uprooted tree trunk on the sands suddenly change into a hippopotamus and make its way into the sea.

"Hippopotamuses travel by sea to get from one estuary to another, no doubt ridding themselves at the same time of certain parasites in the salt water."

Hippopotamuses show no more aquatic adaptation than the sauropod dinosaur, *Diplodocus*, if as much. Hippopotamuses are confined in their present range to Africa south of the Sahara, being found in the Nile only above Khartum. In former times they extended to Madagascar, northwest India and practically the whole of western Europe including southwest England (Murray 1866, map XXIX). This shows that certain barriers exist which prove effective against such extremely mobile creatures as the deer and which have debarred them from the Ethiopian realm. These barriers, however, were not prohibitive in the case of the less mobile hippopotamus. A similar contrast of conditions might readily have limited the distribution of the Orthopod dinosaurs, while the Sauropoda, as in the case of the hippopotamuses, could easily migrate.

Why the Sauropoda lingered so long in the southern hemisphere after their apparent extinction in the North, is difficult to answer unless it were because of the limitations of food and climate in the North which did not at once prevail in the South. Even though the Trachodontidæ gradually assumed aquatic habits, they were too late to be brought into active competition with the Sauropoda in the northern land mass.

The carnivores being always present doubtless served at first only to limit the plant-feeding forms; they may, however, have been responsible for the final blotting out of the Sauropoda when weakened in numbers and by the burden of racial old age.

I believe that, all things considered, the degree of moisture, whether atmospheric in accelerating or limiting plant growth, or in the form of actual water barriers, was the most potent factor in the origin, evolution, migrations, and final extinction of the dinosaurian race.

Williston (1909, p. 401) is inclined to think that "there must have been free communication during part or all of the Mesozoic time between North and South America, proof of which is seen in the dinosaurs, mosasaurs, and crocodiles, some of them being, according to competent observers, identical generically even with North American forms." This may be true of the crocodiles and mosasaurs and yet imply no land bridge over which dinosaurs could pass. True, fragmentary remains from Patagonia have been referred to *Allosaurus* so characteristic of the American Morrison, but I seriously question the generic identity of any of the dinosaurs with North American forms. The presence of the earliest recorded remains near Bahia, on the line of march from the East, may be taken at its apparent value. I have found no evidence in favor of a north and south migration in the western hemisphere.

These studies only serve to verify for the most part the paleogeographical maps of de Lapparent and Schuchert, for in every instance, with the exception of Patagonia and where the dinosaur was found in salt water deposits, the locality fell upon a land area as indicated upon the maps. I would, however, differ from de Lapparent in his inclusion of New Zealand in the Gondwana continent after the beginning of the Trias. The finding of similar dinosaurs on either side of the Mozambique Channel during the Cenomanian, after the cleavage of Gondwana Land into an Indo-Madagascar and an Africo-Brazilian mass, has been explained by Depéret (1909, p. 303), who assumes that a temporary closure of the gap occurred. As the Madagascar types are mainly Sauropod, one of which was found associated with *Mytilus* and Foraminifera, the closure may not have been complete. It is not, however, necessary

to assume even a partial closure, as my map (fig. 9) will show. De Lapparent's maps show no connection between Gondwana Land and Patagonia until the Basal Eocene, which is too late for the migration of the Patagonian (Danian) dinosaurs from the northeast. The closure may have occurred not long before, however, so far as dinosaurian evidence is concerned.

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ART. II.—*The Origin of the Crinoidal Muscular Articulations*; by AUSTIN HOBART CLARK.

THE peculiarly complicated type of muscular articulation by which the post-radial ossicles of the crinoids are joined together is generally supposed to have been derived from the so-called loose suture, the connective tissue of which has gradually become differentiated into two different types of ligaments and also into true muscle. The steps by which this process has come about have never been satisfactorily shown.

While there appears to be in the crinoids a direct continuity between the connective tissue through various types of ligamentous attachment to true muscle, yet it does not seem probable that the differentiation of the connective tissue between two adjacent ossicles could ever have progressed so far as to produce the conditions found in the crinoids, where two bundles of highly specialized muscle fibers occur, histologically, as well as in their location, sharply differentiated from the ligaments.

A comparison of the crinoids with the two most nearly related recent classes, the Echinoidea and the Holothuroidea (Bohadschoidea), offers, however, an easy solution of the problem of the origin of the complex crinoidal muscular articulations.

In the Echinoidea the plates are united more or less closely by connective tissue, just as are the interradians and the secondary perisomic plates generally in the recent crinoids, and this was probably the original mode of union for the primary ambulacral ossicles of the crinoids as well. Now in all the heteroradiate Echinodermata (which include the Pelmatozoa, Echinoidea, and Holothuroidea) wherever the ambulacral ossicles or body wall are at all flexible, as occurs in the crinoids, in the holothurians, and in the echinothurids among the echinoids, each ambulacrum possesses a pair of longitudinal muscles one of which runs along either outer border, and may extend itself more or less inward. No definite homology has ever been proved between these five longitudinal ambulacral muscle pairs which are so constant in all the recent heteroradiate Echinodermata possessing the possibility of ambulacral motion; but from the uniform presence and location of these muscles it seems most probable that such homology actually exists.

Now if the ancestral crinoids possessed a longitudinal muscle along each border of the ambulacral series, as we must infer from analogy with the echinothurids and the holothurians, their closest recent relatives, we may assume an ambulacral structure something like that of the former—a series of

ambulacral ossicles united by connective tissue with a longitudinal muscle band running interiorly along either side of the ambulacral series as a whole. It is easy to imagine that at first the muscle bands were fanlike in arrangement and broad as in the echinothurids, but later, with increased flexibility of the test, became narrow, and finally resolved themselves into longitudinal muscles more like those of the holothurians. With increased scope of motion between the ambulacral ossicles, beveling was induced, whereby the apposed faces of adjacent ossicles were in close apposition in the median line (perpendicular to the line between the center of the ossicle and the center of the calyx) but sloped away from each other both inwardly and outwardly. The connective tissue along this median line, the prototype of the so-called transverse ridge, now became very short and dense, forming what is practically a very narrowly linear close suture; while the connective tissue on the remainder of the articular surfaces was more or less lengthened, and gradually became ligamentous in nature, at the same time, through the separation of the internal edges of adjacent ossicles, the longitudinal muscle bands were, by pressure from within the calyx, pushed in between them, and certain of the fibers came to be inserted on the apposed faces of the ossicles instead of only on the ventral (interior) surface. This would give the ambulacral ossicles a joint face consisting of two equal oblong ligament fossæ, separated by a narrow transverse ridge, with a small muscular fossa at each outer corner of the inner ligament fossa. Now the calyx of the crinoids is remarkable for its very small size, and hence in the development of the race we may assume that this decrease in size has caused it to press more or less upon the internal organs. This pressure would not be equal at all points on the inner surface of the ossicles because of the existence of various radial vessels which run along the center of the ambulacra, chief among which is the axial nerve cord. These vessels would, by this pressure, encroach upon the area of the inner ligament fossa, and would tend to excavate it in the form of a more or less broad V, at the apex of which would be the axial nerve cord; at the same time the muscles would encroach more and more upon the articular face, and the part of the original muscular band which originally ran along the inner side of each individual ossicle, having now become useless, would disappear. The ventral ligament fibers, as a result of the decrease in the area of the fossa occupied by them through the encroachment of the "soft parts," not being able to migrate past the close suture along the transverse ridge, would come to lie more and more closely together, and would form two masses each more dense and compact than that of



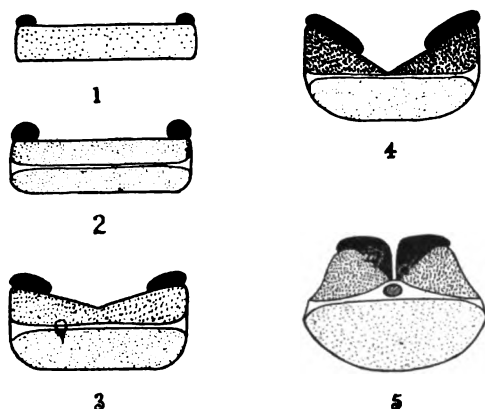
the outer (dorsal) ligament mass, which remains unchanged. The muscles, unable to penetrate into the area occupied by the two resultants from the originally single inner (ventral) ligament mass, would gradually creep inward along their outer edge toward the center of the joint face. When the encroachment of the "soft parts" had progressed so far as to cause the axial nerve cord to lie upon the transverse ridge, we would find a condition as follows: first a large undivided dorsal ligament fossa occupied by more or less scattered contractile ligament, and bounded ventrally by the transverse ridge; just ventral to the transverse ridge would be found two triangular fossæ, one on either side, lying with their apices just under the center of the axial cord and one of their sides coinciding with the transverse ridge; these fossæ would lodge ligament masses similar to the dorsal ligament mass, but much more dense; on the outer distal corners of each of these two triangular fossæ would be found muscular fossæ, which would extend more or less inward toward the center of the joint face, but which would never meet in the median line. Thus we have arrived at the type of muscular articulation characteristic of the crinoid arm, comprising a single dorsal ligament fossa, two interarticular muscular fossæ, and two ventral muscular fossæ. This theory of the genesis of the crinoidal muscular articulations (1) explains the peculiar denseness of the interarticular ligament masses, and (2) does away with the necessity of assuming that the muscles are the specialized connective tissue of an original loose suture.

I have already shown how the peculiarly modified non-muscular articulations, the syzygy and the synarthry, are derived from the muscular type of articulation; so that now we are enabled to derive every known type of union between the ossicles of the crinoid crown from the simple connective tissue union known as the loose suture.

A few words in regard to the syzygy may not be out of place. Minckert, like all his predecessors except Sars, believes that the syzygies are joints of especial weakness in the crinoid arm where fracture takes place in case the arm is seized, due to this especial weakness. He also believes that in adolescent autotomy the arm is voluntarily cast off by the animal at the first syzygy. My experience with living crinoids has led me to agree with Sars; the syzygy is at least as strong as the muscular articulations, as anyone may prove for himself by breaking up crinoid arms. Under certain conditions, however, the syzygy becomes peculiarly weak, and often breaks of itself. I believe that this is susceptible of ready physiological explanation. Bosshard has shown that the fibers of the dorsal ligament and of the syzygy are histologically the same, the only

difference being that the latter are extremely short. Now since the fibers of the dorsal ligament and of the syzygy are identical except in length, we should expect that they both would possess the same physiological characteristics, and, therefore, that the fibers of the syzygy would be contractile in the same way that those of the dorsal ligament are, though their possible loss or gain in length, owing to their shortness, would be very slight. As the fibers of the syzygy are continuous in substance through the organic base of the ossicles with those of the dorsal ligaments preceding and succeeding, it is probable

FIGS. 1-5.



*Diagrams illustrating the origin of the muscular articulations of Crinoids.*

FIG. 1. The primitive joint face, with connective tissue binding; the two longitudinal ambulacral muscles are seen on the outer angles.

FIG. 2. A joint face differentiated by the development of a transverse ridge; the connective tissue on either side has become ligamentous, and the muscles have increased in size.

FIG. 3. A joint face showing reduction of the internal fossa by pressure of the "soft parts;" the ligament of the internal fossa is becoming denser; the muscles have increased in size.

FIG. 4. The internal fossa has now become divided into two interarticular ligament fossae, lodging dense ligament bundles; the muscles have become still larger.

FIG. 5. Radial face of one of the *Zygometridae*.

that they act in sympathy with them, expanding and contracting, in their small way as they do. It may be readily supposed that the tension of the fibers in the syzygy is adjusted to the ordinary movements of the crinoid arm. The dorsal ligaments are normally always antagonized more or less by the powerful ventral musculature and ordinarily never contract to their furthest capacity. If for any reason the ventral muscles are rendered inert, as by the panic incident to capture, then

the dorsal ligament would contract to the farthest limit, and the fibers in the syzygies, through sympathetic action, would also contract, but, being normally under more or less tension, would not be able to take up this contraction within themselves, but would be pulled apart, thus breaking off the arm at the syzygy. Fracture of the arms at the syzygies, then, would appear to be an entirely involuntary act on the part of the crinoid, due solely to the physiological effects of panic; this panic may, of course, be more or less general, or localized, so that stimulus of the calyx would induce fracture at the first brachial syzygy, stimulus on the arms at the neighboring syzygies.

During the growth of most of the oligophreate comatulids the ten original arms are cast off, often at the first syzygy, and from the stumps axillaries arise bearing several arms. Minckert supposed that this was a voluntary action; but it is noticeable that all the comatulids which have more than ten arms have short brachials which are correlated with a corresponding shortness in the muscle fibers and dorsal ligament fibers uniting them. Now it seems probable that during growth the dorsal ligament fibers are able to accommodate themselves gradually to their decreasing length through their contractile power; but this would have exactly the same effect upon the syzygies as panic—they would be torn apart—so that the casting off of the arms of the ten armed young of the oligophreate comatulids appears to be, not a voluntary action, but a direct result of the gradual change from the juvenile to the adult type of brachial.

ART. III.—*On the Substitution of Bromine and of Iodine for Chlorine in the Separation of Cerium from the other Cerium Earths*; by PHILIP E. BROWNING and EDWIN J. ROBERTS.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cevi.]

ONE of the best known processes for the separation of cerium from lanthanum and didymium is that of Mosander.\* This process consists in passing chlorine gas into a mixture of the hydroxides suspended in a distinct excess of a fixed alkali hydroxide, until the solution is saturated and the reaction of the liquid is no longer alkaline to litmus. Under these conditions nearly all the cerium remains undissolved as the ceric hydroxide, while the other cerium earths go largely into solution. In treating mixed material the residue of ceric hydroxide generally retains some of the cerium earths so that the treatment with chlorine must be repeated. Two disadvantages associated with this method therefore are, the preparation and use of chlorine gas, and the solvent action of the hydrochloric acid formed in the reaction upon the ceric hydroxide



The work to be described was undertaken to study the effect of substituting bromine or iodine for chlorine in this process. A preliminary experiment was made by suspending a precipitate of the washed hydroxides of the cerium earths in water, adding a little liquid bromine, and allowing the action to go on for several hours with occasional stirring. The precipitate took on the color of the ceric hydroxide, and on filtering the filtrate was found to contain a considerable amount of cerium earths free from cerium.

In the following experiments solutions of known amounts of the mixed oxides, composed of about 50 per cent of cerium and 50 per cent of the cerium earth oxides other than cerium, were treated with a slight excess of sodium or potassium hydroxide. To these hydroxides suspended in the alkaline solution, liquid bromine or bromine water was added in distinct excess, and the mixture was placed upon a steam bath until the greater part of the free bromine was expelled. The residue was then filtered off, washed, and treated as before. This process was repeated twice, and the filtrate after each treatment was found to contain the amounts of cerium earth oxides, free from cerium, indicated in the table. The residue from the last treatment on being dissolved in acid showed only

\* J. prakt. Chem., xxx, 267.

faint didymium bands. In experiment (6) the indication of the presence of didymium was very faint. In another experiment the same amount of material used in (5) and (6), 10 grams, was subjected to a fourth and fifth treatment with bromine, the fourth treatment yielding a small fraction of a gram of the oxides, and the fifth only a few milligrams. In both cases these oxides were free from cerium. The oxides from the first filtrates were much lighter in color than those obtained from the last, which, of course, indicates that the lanthanum is dissolved by the action of the bromine more readily than the didymium. The results follow in the table :

	Mixed oxides taken gram.	Oxides found in first filtrate gram.	Oxides found in second filtrate gram.	Oxides found in third filtrate gram.	Total oxides found gram.
(1)	1·0000	0·3310	0·0720	0·0190	0·4420
(2)	1·0000	0·2900	0·1010	0·0420	0·4330
(3)	1·0000	0·2250	0·1290	0·0640	0·4180
(4)	1·0000	0·2750	0·0860	0·0740	0·4350
(5)	10·0000	3·1360	1·0050	0·5930	4·7340
(6)	10·0000	3·4590	0·5240	0·8560	4·8390

So it has been shown that by substituting bromine for chlorine in the Mosander process about 50 per cent of the other cerium earths can be separated from ceric hydroxide in one treatment, and that after three treatments practically all the other cerium earths are removed without any solvent action upon the ceric hydroxide. The advantages of the method are, the convenience in the use of the bromine, and the apparent lack of tendency of the hydrobromic acid to dissolve the ceric hydroxide.

An experiment was made, using iodine in place of bromine, as follows : The precipitated and suspended hydroxides from 2 grams of the mixed oxides were treated with 1 gram of solid iodine. After standing for about two hours on a steam bath, the excess of iodine was removed by boiling, and the residue of hydroxides was filtered off. The filtrate gave 0·0980 gram. of oxides, free from cerium, and of a slight brown color. This shows that the action of iodine is the same, in a general way, as that of chlorine and bromine, but is too incomplete to be of any practical value.

ART. IV.—*New Fossil Coleoptera from Florissant, with Notes on some already described*; by H. F. WICKHAM.

*Calosoma* Web.

*C. cockerelli* n. sp. A piece of a wing cover lacking both base and apex is referred to this genus. It represents a species about the size of *C. calvini* m., from the same shales. The elytron is marked with sixteen well impressed punctured striæ, besides an indeterminate number (perhaps two) closer to the outer margin. The interspaces are nearly four times as wide as the diameter of the punctures in most parts of the area, but in the neighborhood of the apex of the tenth and eleventh striæ the punctures are much larger than elsewhere and are equal in diameter to the interstitial width. In general, the punctures are rounded or slightly elongate and they are separated longitudinally by spaces about equal to their own diameters. The elytral surface shows no indication of the coarse imbricate scabrosity of the interstitial spaces which is evident in our recent North American *C. calidum*, nor are any series of interstitial punctures visible. The interspaces are apparently slightly convex. Length of fragment about 9·25<sup>mm</sup>, greatest width 6·15<sup>mm</sup>.

Station number not given. Collection number 232, Florissant Expedition 1906. Received from Prof. Cockerell. Holotype in Peabody Museum of Yale University. Cat. No. 10.

*Pterostichus* Bon.

*P. pumpellyi* Scudder. An elytron showing obverse and reverse is referred here with fair certainty. The elytral striæ are nine in number and are more clearly exhibited on the reverse. They are fine, sharp, fairly deep, perfectly smooth, the interspaces moderately convex. The scutellar stria joins the first at about 1·75<sup>mm</sup> from the base. Length 9·75<sup>mm</sup>, width 3·40<sup>mm</sup>.

Station number 13. Collection number, obverse 87, reverse 65, Florissant Expedition 1906. Received from Prof. Cockerell.

*Platynus* Bon.

A specimen in obverse and reverse, believed to belong to this genus, is among the material sent by Prof. Cockerell. The elytra are 6·20<sup>mm</sup> in length, and have a conjoint width of 4·10<sup>mm</sup> at middle. They are finely striate, about as in our recent *P. placidus*, and are apparently almost or quite impunc-

tate. Compared with *P. tartareus* Scudder, from the Florissant shales, the specimen in hand has the humeral angles less rounded and the elytral apices decidedly less truncate. The remainder of the body is too poorly preserved for study, and it seems scarcely wise to impose a specific name.

Station number 13a. Collection numbers 114 and 155, Florissant Expedition 1906. Collected by Mrs. W. P. Cockerell, and received from Professor Cockerell. Specimen in the Peabody Museum of Yale University, Cat. No. 11.

*Peltis* Illiger.

*P. laminata* n. sp. Form oblong-elliptical, similar to that of the recent North American *P. pipingskeldi*. Head larger than in that species, somewhat dilated by pressure. Prothorax, as preserved, broader shortly in front of the base, sides arcuately narrowed to apex which is broadly emarginate, front angles a little greater than right, hind angles obscure but apparently obtuse and rounding, a faint basal marginal line somewhat as in Colorado specimens of the recent *P. ferruginea*. Elytra slightly broadest at base, where they are a little wider than the prothorax, scarcely perceptibly narrower to a point behind the middle, thence rapidly arcuately narrowed to the apices, which are nearly pointed and (through distortion) dehiscent. The disk shows traces of having been finely striate but the sculpture of the entire surface is now scabrous and obscure. The sexual organs are protruded from the tip of the body but show no definite structure. Length, including extruded sex organ, 12.50<sup>mm</sup>; of prothorax along median line, 2.25<sup>mm</sup>; of elytra, 6.60<sup>mm</sup>; width of prothorax, 5<sup>mm</sup>; of elytra conjoined, 6.25<sup>mm</sup>.

In outline, this insect quite closely recalls several recent species of *Peltis*, though the form of the thorax is slightly nearer that of *Calitys scabra*. However, the thoracic and elytral margins are perfectly clear-cut and entire as in *Peltis*, while in our *Calitys* they are coarsely serrate. The antennæ and legs are not shown.

Station number R. 4. Collection number 145, Florissant Expedition 1906. Received from Prof. Cockerell. Holotype in the Peabody Museum of Yale University, Cat. No. 12.

*Atænius* Harold.

*A. patescens* Scudder. One specimen, in reverse, exceeding Scudder's measurements by about .50<sup>mm</sup>, is included in the collection. The state of preservation is only fair and no important characters can be added to the original description.

Station number 14. Collection number 207, Florissant Expedition 1906. Received from Prof. Cockerell.

*Aphodius* Illiger.

*A. laminicola* n. sp. Form stout, evidently a little more so than in the recent *A. fimetarius*, head narrowed anteriorly, clypeus almost squarely truncate at middle, the angles rounded. Prothorax broadest about the middle, sides apparently regularly arcuate but not alike in the specimen and therefore incapable of exact definition. The appearance is that the base was distinctly broader than the apex. Sculpture obliterated by the impressions of the underside, which show through. Scutellum (?) large, almost equilaterally triangular, the basal (anterior) angles obliquely truncate, basal region rugosely punctate, middle finely carinate. Elytra subparallel to an indeterminate distance behind the middle, regularly conjointly rounded at tip, striae fine, single, finely and not closely punctured, interspaces broad and very nearly or quite flat with a few scattered fine punctures, sutural interval narrower than the next. Legs stout, middle tibia slightly bent at base, tip moderately expanded, median oblique ridge faintly indicated. Length 9.70<sup>mm</sup>, of elytra 5.75<sup>mm</sup>, of middle femur about 1.70<sup>mm</sup>, of middle tibia 1.35<sup>mm</sup>, of middle tarsus about 1.35<sup>mm</sup>, conjoint width of elytra about middle 4.80<sup>mm</sup>.

Station number 14. Collection number 231, Florissant Expedition 1906. Received from Prof. Cockerell. The type is in the Peabody Museum of Yale University (Cat. No. 13); a second, poorer specimen, a reverse, from the same station and with the catalogue number 140, is in the Museum of the University of Colorado.

The type specimen is very puzzling, on account of the peculiar state of preservation; the parts of the under side are largely shown through and interfere with the view of the upper surface. Thus I am not sure whether the structure described as the scutellum may not be the mesosternum, and on account of similar confusion I have not tried to give measurements for the head and prothorax. Of the legs, the two middle femora show plainly, the front and hind ones indistinctly. One middle tibia and the tarsus of the opposite leg are distinct.

*Amphicoma* Latr.

*A. defuncta* n. sp. The specimen shows only the tips of the elytra, with ill-defined exposed portions of the abdominal apex, some traces of hind wings, a well preserved hind tibia and tarsus and poorly indicated portions of the other leg of this pair. Elytra strongly dehiscent and tapering to the tip, which is rounded, surface clothed with hairs which are apparently longer and sparser than in the recent California *A. ursina*. The outer edge of each elytron shows a fine marginal bead, as in that species; the sutural bead is less strongly marked. No



indication of discal sculpture, aside from the fine piligerous punctures, can be seen. The exposed tibia of the hind leg is perhaps a trifle stouter than in *A. ursina*, about equally broadened to the tip, the lateral margins (perhaps accidentally) irregular; one terminal spur shows, which is more than half as long as the first tarsal joint, but the extreme apex is concealed so that the exact length cannot be determined. Tarsi rather stout for this genus, the first joint longest (about one third longer than the one following) third and fourth joints nearly equal to each other and slightly longer than the second, claw joint again longer but ill defined, claws not in condition for study. Apparently, the first, second and third tarsal joints were finely longitudinally carinate above, a feature that I cannot detect in any recent *Amphicoma* at my disposal. Neither do I find any certain evidence that the legs were hairy, though I believe that certain sculpturings on the tibia represent piligerous punctures. The tarsal joints surely bore short stiff hairs on their margins, as in the recent *A. vulpina* from the New England coast. Width of elytral fragment, at 5<sup>mm</sup> from tip, 3<sup>mm</sup>; length of tibia, 4.75<sup>mm</sup>; of tarsus, entire, 7.25<sup>mm</sup>; of first joint about 1.75<sup>mm</sup>.

Station number 14. Collection number 186, Florissant Expedition 1906. Received from Prof. Cockerell. The holotype is in the Peabody Museum of Yale University, Cat. No. 14.

#### *Lema* Fabr.

*L. evanescens* n. sp. Form similar to that of the recent *L. collaris* and equally stout. As the type is largely in profile, it is not possible to give comparative measurements of the length and breadth of different parts of the body, though the head, with greater portions of the eyes and antennæ, the prothorax, elytra, abdomen, and parts of the legs are more or less clearly shown. The antennæ are very nearly approximate at base and are stout, the intermediate joints but very little longer than broad; the eyes are large and prominent, legs stout. The specimen is a reverse, and lines of small elevations indicate that the elytra were punctured in rows similarly to most of our recent North American species. Total length, 5.60<sup>mm</sup>; of elytron, 3.60<sup>mm</sup>.

Station number not given. Collection number 86, Florissant Expedition 1906. Received from Prof. Cockerell. Type in Peabody Museum of Yale University, Cat. No. 15.

A second specimen, collected at Florissant in 1906 but with no station designated though bearing the collection number 107, is less in profile than the first and indicates that the prothoracic constriction was slightly antemedian and fairly deep. In this the broader elytron is 3.65<sup>mm</sup> in length and about 1.30<sup>mm</sup> in width.

*Ologlyptus* Lacordaire.

*O. primus* n. sp. The rather poorly preserved specimen indicates a species of moderate size and probably flattened form, approximating that of our recent *O. anastomosis*. The prothorax is broadest near the middle, sides regularly rounding, apex considerably narrower than the base but owing to incompleteness of the specimen the exact proportions cannot be given. Head obscured, antennæ with the median joints about as broad as long. Elytral sculpture apparently rough, but no details can be made out. Legs wanting. Length of specimen, which lacks a small portion of the tip of the elytra, 7.25<sup>mm</sup>; of prothorax about 2.15<sup>mm</sup>; width of elytra, conjoint, 3.65<sup>mm</sup>; of prothorax (distorted?), 2.75<sup>mm</sup>.

Station number 13. Collection number 154, Florissant Expedition 1906. Received from Prof. Cockerell. Holotype in the Peabody Museum of Yale University, Cat. No. 16.

The generic reference is not made with any great certainty, but the facies is decidedly that of several recent species of *Ologlyptus*, with which it has been directly compared. The prothorax appears to have the basal margin extending farther backwards than the points of the hind angles, much as in the Mexican *O. sinuaticollis* but to an even greater degree.

*Macratia* Newm.

*M. gigantea* n. sp. Form elongate, head small, short, prothorax very long and narrow, elytra conjointly much broader than the prothorax, sides subparallel, apices rounded, surface finely, distinctly and rather closely striate, the striæ finely, not closely punctured, interspaces flat. Middle leg not elongate and only moderately stout. Antennæ showing only a few intermediate joints which are sufficiently well preserved to indicate that they are longer than wide, but not greatly elongate. Length from front of head to tip of elytra, but exclusive of projecting abdominal organs, 8<sup>mm</sup>. Length of head, as preserved, 1<sup>mm</sup>; of prothorax, 2.10<sup>mm</sup>; of elytra, 5.10<sup>mm</sup>. Width of prothorax about 1.50<sup>mm</sup>, of elytra, conjointly, 2.50<sup>mm</sup>. The articulations of the leg joints are not well enough defined to permit of accurate measurements.

Station number 14. Collection number 9, Florissant Expedition 1906. Received from Prof. Cockerell. Holotype in the Peabody Museum of Yale University, Cat. No. 17.

The specimen has a decidedly Anthicide look, and in build as well as sculpture resembles our recent North American species of *Macratia* though far exceeding them in size. Possibly it may represent an extinct allied genus, but no characters are evident upon which to base a separation.

Iowa City, Iowa.

ART. V.—*A Feldspar from Linosa and the Existence of Soda Anorthite (Carnegieite)*; by HENRY S. WASHINGTON and FRED. EUGENE WRIGHT.

THE mineral described in this paper was found as loose crystals, together with crystals of kaersutite, at a small parasitic, cinder cone of the volcano Monte Rosso, on the island of Linosa, east of Tunis.\* The chemical investigation was undertaken by the senior author and the optical by the junior.

*Physical Characters.*

The dark brown, pumiceous, basaltic lava clings so tenaciously to the crystal faces that it was not possible to obtain satisfactory material for crystallographic measurements. The crystals vary much in size, the largest one measuring 3.5<sup>cm</sup> in length and about 2<sup>cm</sup> in width. While some are fragmentary, others are wholly bounded by crystal faces. They are elongated parallel to the *a* axis, and are of simple crystal habit, being bounded by the forms (001), (010), (110), and (1 $\bar{1}$ 0), on the assumption that the mineral is a triclinic feldspar.

Although the crystal faces do not lend themselves to goniometric measurement, the basal cleavage is highly perfect, and albite twinning lamellæ are occasionally well developed. On such a cleavage flake the angle between the basal cleavage planes of two adjacent albite lamellæ was measured on a two-circle goniometer with reducing attachment, and found to be 8° 3'. From this the angle (001)  $\wedge$  (010) = 85° 59' can be deduced, this angle for albite being 86° 24', for anorthite 85° 20', and for labradorite 86° 12'. The cleavage after (010) is very imperfect, as is often the case with the soda-lime feldspars, and only indications of cleavage after the prism faces (110) and (1 $\bar{1}$ 0) were noted. When the cleavage does not control, the fracture is highly conchoidal. Viewed along certain directions, especially about normal to the front pinacoid, a peculiar, milky, opalescent sheen, resembling that of moonstone, can be seen in some of the crystals.

Fine polysynthetic twinning lamellæ after the albite law are not uncommon, and occasionally cross polysynthetic twinning lamellæ, probably after the pericline law, were observed. On a plate nearly normal to the obtuse bisectrix the angle between the albite and the pericline twinning lamellæ was found to be 94°.

The specific gravity was determined (by H. S. W.) with the pycnometer on two separate portions of the carefully selected

\* Cf. H. S. Washington, *Jour. Geol.*, vol. xvi, p. 10, 1908; and Washington and Wright, this *Journal*, vol. xxvi, p. 187, 1908.

material used for the chemical analyses, and was found to be 2.692 at 3° and 2.693 at 17°. The latter may, therefore, be considered to be the specific gravity of the mineral, or, rather, correcting for about 0.75 weight per cent, or 0.35 volume per cent, of included magnetite, the true specific gravity of the mineral would be 2.684. The hardness is slightly less than that of adularia, but not far from 6.

Except for ferruginous stains derived from the inclosing basaltic scoria on the exterior portions of the crystals, and the very small and rare inclusions of magnetite to be described later, and which did not interfere with the optic determinations, the material is remarkably fresh, colorless and transparent, and admirably adapted for optic work. Zonal structure was not evident.

The refractive indices were measured in sodium light on an Abbé-Pulfrich total refractometer, the probable error of the values being less than  $\pm 0.001$ , with the following results:

$$\alpha_{Na} = 1.5549, \beta_{Na} = 1.5587, \gamma_{Na} = 1.5634, \\ \gamma - \alpha = 0.0085, \gamma - \beta = 0.0047, \beta - \alpha = 0.0038$$

According to these values the measured crystal plate was optically positive and  $2V_{Na} = 82^\circ 48'$ . On a second, less perfect plate slightly higher values were obtained, but the observed differences were only a little greater than the probable error.

The optic axial angle was measured directly on a Wülfing axial angle apparatus in sodium light, the plates being immersed in a liquid of the refractive index 1.559, the observed readings giving, therefore, at once the true optic axial angle  $2V_{Na}$ . Five plates normal to the bisectrix  $c$  and one plate normal to  $a$  were measured. The values thus obtained did not agree well, and several of the plates were remeasured with practically the same results.\* The probable error of the values in the following table is certainly less than  $\pm 30'$ .

Crystal plate	$2V_{Na}$	Dispersion	Optical character	Extinction angle, † $\alpha \wedge a$
1	$78^\circ 0'$	$\rho > v$	+	$28.0^\circ$
2	$78^\circ 29'$	----	+	$12.0^\circ$
3	$84^\circ 29'$	$\rho > v$	+	$6.2^\circ$
4 †	$85^\circ 41'$	----	+	$33.0^\circ$
5	$89^\circ 27' \S$	----	—	$11.9^\circ$
6	$88^\circ 59' \parallel$	----	—	$13.0^\circ$

\* We are indebted to Mr. E. S. Larsen, jr., of the Geophysical Laboratory, for an independent measurement of the optic axial angles of the entire set. His results are practically the same as those in the table, the greatest differences being  $20'$  on a less favorable plate.

† Too much stress cannot be placed on these extinction angles, since the plates were cut only approximately normal to the bisectrices and were out a number of degrees in certain instances.

‡ Plate cut normal to the obtuse bisectrix.  $94^\circ 18'$  measured.

§  $90^\circ 33'$  measured.

||  $91^\circ 1'$  measured.

These variations are of considerable magnitude and the values seem to differ from crystal to crystal rather than within a single crystal. This phenomenon of variation in optic axial angle might possibly be explained as a result of unequal cooling of the different crystals, as is the case with orthoclase and sanidine; but other evidence, particularly that of the extinction angles, shows that the composition probably varies slightly from crystal to crystal.

The extinction angles were measured both on cleavage flakes after (001) and on (010). In each case the angles were measured as accurately as possible, with the aid of the circularly polarizing bi-quartz wedge,\* and the probable error is less than 15'.

On (001) the values for  $\alpha \wedge a$  ranged from  $-0.6^\circ$  to  $-4.5^\circ$ , and on basal cleavage flakes from one crystal the angles averaged  $-2.0^\circ$ , and from a second  $-4.5^\circ$ . Other pieces showing polysynthetic lamellæ were observed occasionally with very high extinction angles; but the examination in convergent light, and also the determination of the ellipsoidal axis, whether  $a$  or  $c$ , proved that either the cleavage fragment was not parallel to the base or that pericline lamellæ were being examined.†

Extinction angles were also measured on the brachypinacoid (010), both on the rhomb-shaped cleavage flakes and also on a section ground parallel to the brachypinacoid. Different values were obtained for different flakes, although in the larger ground plates no marked indications of wavy extinction or zonal structure were observed. The values ranged from  $\alpha \wedge a = -2.5^\circ$  to  $-11^\circ$ . Since, however, the cleavage parallel to (010) is not perfect, it is possible that part of this variation was due to the fact that the surfaces were not precisely parallel to (010) at the place of measurement, but were inclined because of minute irregularities of the cleavage. Flakes parallel to (010) often show in white light the peculiar interference phenomena characteristic of minerals with slight dispersion of the bisectrices.

In convergent polarized light the optic normal emerges near the center of the field on plates parallel to (001); while the bisectrix  $c$  is nearly normal to the brachypinacoid, and appears near the center of the field on flakes parallel to (010).

Taken collectively, these results indicate that the present material is a plagioclase feldspar, of somewhat variable composition and with slightly modified characters. Taken alone,

\* Cf. F. E. Wright, this Journal, vol. xxvi, p 391, 1908.

† A series of measurements on 12 different cleavage flakes from one of the crystals was also made by Mr. E. S. Larsen, with the result  $\alpha \wedge a = 2^\circ 2' \pm 6'$ , a value well in accord with Wright's observations.

the extinction angles on (001) would indicate a feldspar composition ranging from about  $Ab_{11}An_9$  to  $Ab_{11}An_{10}$ , while from those on (010) a composition from  $Ab_{11}An_9$  to  $Ab_{11}An_{10}$  and higher might be inferred. The values of the optic axial angle alone indicate variations from  $Ab_{11}An_{10}$  to  $Ab_{11}An_{11}$ , according to the most accurate measurements of the different members of the plagioclase series. As a whole, therefore, the optic characters would show that we have an andesine feldspar of a composition somewhat more sodic than  $Ab_{11}An_{11}$ , on an average about  $Ab_{11}An_{11}$ , while the specific gravity is almost exactly that of a labradorite of the composition  $Ab_{11}An_{11}$ , or (corrected) of an andesine  $Ab_{11}An_{11}$ .

#### *Chemical Composition.*

The material used for the chemical analyses was obtained by coarsely crushing several of the crystals and fragments and very careful hand-picking under the lens. It was found to be impossible to separate the portions contaminated with adherent basaltic scoria by means of heavy solutions. Because of the similar specific gravities, particles with and without attached scoria floated and sank together. In the heavy solution the material used for analysis seemed to be homogeneous.

All the material analyzed was perfectly fresh, colorless, and water-clear, and consisted of but one mineral, so far as could be ascertained by examination under the microscope. While the greater portion was entirely free from inclusions, it was impracticable not to use some fragments containing inclusions, and as these have a bearing on the chemical discussion, they may be briefly described here. Apart from them the material was perfectly pure and admirably suitable for chemical analysis.

The inclusions are never very abundant, especially in the fragments used for the analyses. They are very minute in size, the largest being 0.5<sup>mm</sup> long by 0.1<sup>mm</sup> wide, and the great majority are much smaller. They are of uniform character, in the form of narrow, spindle-shaped bodies or thin cylinders with rounded ends. They are black, with metallic luster, and perfectly opaque, so that they may be regarded as essentially magnetite, a conclusion also indicated by the results of the analyses.

The feldspathic mineral is only slightly acted on by hot, dilute hydrochloric acid, even after prolonged treatment, so that the main portion was brought into solution by fusion with mixed sodium and potassium carbonates. In this, as in other respects, the analyses were made by the methods advocated by Hillebrand and by Washington, the alkalies being determined by the Smith method.

An analysis was made in duplicate (except for FeO, the alkalis and H<sub>2</sub>O) on one lot of selected fragments, portions of which also served for the specific gravity determinations, the material being dried at 110°. As the results were decidedly unexpected, especially in view of the preliminary optic work, a second lot of fragments was analyzed, special care being taken to select, so far as possible, only those showing cleavage surfaces, so as to exclude any possible nephelite. The results of the three analyses, with the average and the molecular ratios of this last, are given below.

	I	II	III	Average	
SiO <sub>2</sub> .....	52.73	52.75	52.83	52.77	.874
TiO <sub>2</sub> *.....	trace	trace	trace	trace	
Al <sub>2</sub> O <sub>3</sub> .....	29.34	29.54	29.63	29.50	.290
Fe <sub>2</sub> O <sub>3</sub> .....	0.67	0.75	0.53	0.65	.004
FeO.....	0.17	(0.17)	(0.17)	0.17	.002
MgO.....	0.03	0.05	0.07	0.05	.001
CaO.....	10.73	10.59	10.67	10.66	.190
Na <sub>2</sub> O.....	5.40	(5.40)	(5.40)	5.40	.087
K <sub>2</sub> O.....	0.74	(0.74)	(0.74)	0.74	.008
H <sub>2</sub> O.....	0.38	(0.38)	0.34	0.36	
	100.19	100.37	100.38	100.30	

The very small amounts of iron oxides and magnesia are evidently derived from the small, opaque inclusions. Ferric oxide is in excess of ferrous, but in the determination of such small amounts the fact is not of much significance, so that the figures bear out the microscopic examination in the conclusion that the inclusions are of a (non-titaniferous) magnetite. They also probably contain the magnesia. We may, therefore, safely reject the small amounts of ferric and ferrous oxides, magnesia and water, which last is to be ascribed to adsorption of atmospheric moisture† by the powder. On this basis the composition deduced from the analysis will be as follows:

	Linosa mineral			( $\frac{1}{2}$ Na $_2$ , $\frac{1}{2}$ Ca)Al $_2$ Si $_2$ O $_{10}$	Ab $_1$ An $_1$	Ab $_2$ An $_2$
SiO $_2$	53.26	.882	9.09	52.84	55.67	58.24
Al $_2$ O $_3$	29.78	.291	3.00	29.94	28.26	26.53
CaO	10.76	.192	1.98	10.96	10.34	8.32
Na $_2$ O	5.45	.088	0.99	6.26	5.73	6.91
K $_2$ O	0.75	.008		0.00	0.00	0.00
	100.00			100.00	100.00	100.00

\* The color produced by H<sub>2</sub>O<sub>2</sub> in the solution used for the titration of iron as Fe<sub>2</sub>O<sub>3</sub> was barely perceptible, so that only faint traces of titanium can be present.

† Cf. Day and Allen, Carnegie Publication, No. 31, 1905, p. 57.

The ratios of the Linosa mineral are very close to whole numbers, though there is a slight excess of silica. Calculating the small amount of potash with the soda, the figures of the analysis correspond to the formula  $\text{Na}_2\text{O} \cdot 2\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 9\text{SiO}_2$ , which, simplified, becomes  $(\frac{1}{3}\text{Na}, \frac{2}{3}\text{Ca})\text{Al}_3\text{Si}_3\text{O}_{10}$ . The percentage composition of this molecule is given above.

No anhydrous silicates with formulas corresponding to this appear to be known independently, but several zeolites are analogous, namely: wellsite,  $(\text{K}, \text{Ca}, \text{Ba})\text{Al}_3\text{Si}_3\text{O}_{10} + 3\text{H}_2\text{O}$ ; edingtonite,  $\text{BaAl}_3\text{Si}_3\text{O}_{10} + 3\text{H}_2\text{O}$ ; natrolite,  $\text{Na}_2\text{Al}_3\text{Si}_3\text{O}_{10} + 2\text{H}_2\text{O}$ ; and a potassium natrolite observed by Pirsson\* in missourite with the approximate composition  $(\text{K}, \text{Ca})\text{Al}_3\text{Si}_3\text{O}_{10} + 2\text{H}_2\text{O}$ . Indeed, the composition of the Linosa mineral is exactly that of a mesolite,  $(m\text{Na}, \text{Al}_3\text{Si}_3\text{O}_{10} \cdot 2\text{H}_2\text{O} + n\text{CaAl}_3\text{Si}_3\text{O}_{10} \cdot 3\text{H}_2\text{O})$ , with  $\text{Na}_2\text{O} : \text{CaO} = 1 : 2$ , and lacking the water.

Compounds of this type can be regarded as salts of the alumo-trisilicic acid  $(\text{H}_3\text{Al}_3\text{Si}_3\text{O}_{10})$  of Morozewicz,† the potassium salt of which he considers as present in nephelite, with varying proportions of the sodium alumo-disilicate,  $(\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_7)$ . Reduced to still simpler terms they would be salts of the acid  $\text{H}_2\text{Si}_2\text{O}_7$ , for which Vogt‡ proposes the name pyrosilicic acid. He refers akermanite and gehlenite to this simple formula, as does Tschermak§ the mineral melilite.

Comparing the composition of our mineral with those of the two plagioclases,  $\text{Ab}, \text{An}$ , and  $\text{Ab}, \text{An}$ , which it closely resembles in its physical properties, it will be seen from the table above that  $\text{Ab}, \text{An}$  shows closely concordant figures for lime and soda, while silica is distinctly higher and alumina lower; and that, on the other hand,  $\text{Ab}, \text{An}$  shows much higher silica and slightly higher soda, but lower lime and alumina. In fact a composition satisfactorily close to that of the Linosa mineral as regards all the constituents, and furnishing like ratios, cannot be calculated from mixtures of the albite and anorthite molecules.

The relations may be better seen in the respective ratios, as shown when the formulas are compared, as follows:

Linosa mineral	=	$\text{Na}_2\text{O} \cdot 2\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 9\text{SiO}_2$
Labradorite ( $\text{Ab}, \text{An}$ )	=	$\text{Na}_2\text{O} \cdot 2\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 10\text{SiO}_2$
Andesine ( $\text{Ab}, \text{An}$ )	=	$3\text{Na}_2\text{O} \cdot 4\text{CaO} \cdot 7\text{Al}_2\text{O}_3 \cdot 22\text{SiO}_2$

#### Discussion.

The data given in the preceding pages make it clear that the physical and chemical characters of our mineral are at variance. The crystal system, twinning laws, cleavage, and hardness are

\* Weed and Pirsson, this Journal, ii, p. 320, 1896.

† Morozewicz, Bull. Acad. Sci. Cracov., p. 999, 1907.

‡ Vogt, Mineralbildung in Schmelzmassen, p. 162, 1892.

§ Tschermak, Lehrbuch der Mineralogie, p. 523, 1905.



those of the lime-soda feldspars. The specific gravity, the crystallographic angles measured and the birefringences are those of a labradorite of about the composition  $Ab, An_1$ . Although the optic axial angle and the extinctions are decidedly variable, they correspond to those of andesines somewhat more sodic than  $Ab, An_1$ , on the average about  $Ab, An_1$ . On the other hand, the chemical composition is not that of any possible member of the normal plagioclase series, or mixtures of albite and anorthite. The ratios of  $Al_2O_3$ ,  $CaO$  and  $Na_2O$  are those of  $Ab, An_1$ , but the amount of  $SiO_2$  is lower than that demanded for these by the known feldspar formulas, and the mutual ratios of this with those of the other constituents indicate a composition which corresponds to that of an anhydrous mesolite, or a salt of the acid  $H_2Al_2Si_2O_{10}$ , with  $Na : Ca = 1 : 1$ . Our mineral is, therefore, physically closely allied to labradorite and andesine, but chemical distinctly different in the ratios of the constituents.

The possibility that the material analyzed was a mechanical mixture of particles of two minerals, such as labradorite and nephelite, and that only fragments of the former were subjected to optic investigation, is rendered untenable by the following facts. Careful examination of the unbroken crystals, as well as microscopic study of the crushed fragments and cleavage flakes, by both of the authors independently, revealed the presence of but one mineral, colorless, transparent, cleavable and feldspar-like. Apart from the small, opaque inclusions, each crystal appeared to be homogeneous, and all appeared to be of identical material, except for the optic variations. The action of hydrochloric acid showed that no readily decomposable mineral was present as separate individuals. The very close agreement between separate portions in specific gravity and in chemical composition renders the mathematical chances against the hypothesis of a mechanical mixture of particles of two minerals so great that it may be safely eliminated from consideration. Finally, the lavas of Linosa are all typical feldspar basalts, and only a few very small amounts of nephelite possibly existent as a glassy base. Assuming, therefore, that the material was homogeneous, two hypotheses present themselves to account for the anomalies observed.

One is that the Linosa mineral is to be regarded as a distinct species, chemically, of the formula  $Na_2Ca_2Al_2Si_2O_{10}$ , but with physical properties which correspond very closely to those of a plagioclase of the composition  $Ab, An_1$  to  $Ab, An_2$ . The uniformity of the material as shown by the specific gravity and the chemical analyses and, above all, the very close approach to exact rationality of all the ratios, are in favor of this view. But the peculiarities of chemical composition are explicable in

another way, and as it would be contrary to our notions of the definitions of mineral species to consider two chemically similar minerals as distinct which possess essentially identical crystallographic form and physical and optic properties in so many respects, we may also disregard this hypothesis.

The alternative view is that the mineral is a labradorite of abnormal optic characters and chemical composition, due to the presence of another mineral in intimate molecular mixture as a mixed crystal or solid solution. The amount of this must be small, and in its optic characters the subordinate mineral should presumably resemble a plagioclase, since the optic constants of the Linosa mineral are essentially those of a lime-soda feldspar, but indicate a composition somewhat more sodic than that indicated by the specific gravity.

The range of possibilities as to the mineral molecule which may be supposed to be admixed molecularly with the labradorite is very limited, as it must be, chemically, an aluminosilicate of either soda or lime, or of both of these, with alumina equal molecularly to the basic oxide or oxides, and with the ratio of silica to bases less than in labradorite. Furthermore, it seems necessary to assume that the base is soda alone, because if the subordinate mineral is purely calcic, all the soda entering albite, the lime must be equally distributed between the molecules  $\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$  (anorthite) and  $\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2$ , to obtain the ratios and percentages shown by our mineral. This calcic subsilicate is not known to occur either in nature or artificially, its nearest analogue being kornerupine,  $\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2$ , and its existence does not seem probable. Also no mineral in which  $\text{CaO} + \text{Na}_2\text{O} = \text{Al}_2\text{O}_3$  is known which suits the requirements of the case.

The sodium-aluminum metasilicate,  $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$ , occurs in nature as jadeite, and might also presumably exist as an isometric and isotropic soda-leucite. The presence of this molecule would yield a composition identical with that of our mineral, if soda is equally distributed between this and albite, the whole forming the mixture:  $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2 + \text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 + 4(\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2)$ . But the presence of either of these mineral molecules may be considered as impossible here, on crystallographic as well as on optic grounds.

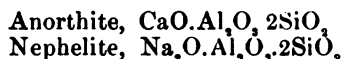
The most probable mineral molecule, therefore, is the orthosilicate  $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ . Assuming this to be present, the composition of the Linosa mineral in terms of mineral molecules can be calculated to be as follows:

$\text{KAlSi}_3\text{O}_8$ .....	·016 }	·154	7·84	4·48
$\text{NaAlSi}_3\text{O}_8$ .....	·137 }			
$\text{CaAl}_2\text{Si}_2\text{O}_8$ .....		·192	9·84	53·78
$\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$ .....		·019	1·00	5·58

Reckoning the small amount of potash as orthoclase with the albite molecule, the ratios of albite, anorthite and sodium aluminosilicate approximate closely to whole numbers, and are almost exactly 8 : 10 : 1. The labradorite would thus have the composition  $Ab, An_8$ , while we have seen that the optic data indicate that the mineral is actually somewhat more sodic, from about  $Ab, An_7$  to  $Ab, An_6$ .

The molecule  $Na_2Al_2Si_2O_8$  is that of potash-free nephelite, which does not seem to occur in nature, but which has been made artificially in small hexagonal crystals, much like those of nephelite, and with a specific gravity of 2.555.\* If this mineral were present it would necessarily be as a mechanical mixture or as what has been termed † an "anomalous solid solution," since it is not crystallographically isomorphous with the triclinic albite and anorthite, and true solid solution or a mixed crystal, containing such an amount of the subordinate mineral as shown above, would hardly be expected in such dissimilar minerals.

True solid solution could take place, however, if the molecule  $Na_2Al_2Si_2O_8$  is dimorphous, and a second form exists whose symmetry relations approximate those of anorthite and albite. The two formulas



are identical, except that in the second  $Na_2O$  replaces the  $CaO$  of the first, and it is not out of the range of possibility that a soda anorthite should exist. This mineral is not yet known to occur in nature, but its presumable characters would harmonize the conflicting data. Thus, it should be triclinic and isomorphous with albite and anorthite, and therefore capable of forming mixed crystals with these analogous to the ordinary plagioclase series. Similarly, it would presumably possess optic characters more sodic, that is, more like those of a soda-lime feldspar, than those of purely calcic anorthite; so that we would thus have an explanation of the fact that, while the relations of  $CaO$  and  $Na_2O$  in our mineral are those of  $Ab, An_8$ , certain of the optic characters are those of a more sodic plagioclase. Since the specific gravity of nephelite, and presumably also of the soda anorthite, is less than that of anorthite, the density of the mixed crystal should be less than that of the equivalent plagioclase in which no soda anorthite occurs, and we have seen that, while the normal plagioclase present is about  $Ab, An_8$ , which would have a density of 2.698, the density of our mineral is that of  $Ab, An_7$  or  $Ab, An_6$ .

\* Cf. Hintze, Mineralogie, vol. ii, p. 97.

† A. Johnsen, Neues Jahrbuch, 1903, ii, p. 93.

From the above data on the percentage composition in terms of the different mineral molecules (Or, Ab, An, Ne), the specific gravity of the mineral can be calculated on the assumption that no great volume change in the component molecules has taken place, a condition which experience has shown to hold true for practically all cases of solid solution. The weight per cent of each molecule present, divided by its density in crystallized condition, furnishes its specific volume or its volume compared with water of equal weight. The sum of these specific volume values for all the molecules present denotes in turn the specific volume of the substance, the reciprocal of which is the density required. In this calculation the most accurate density determinations of the components were used, namely: Or = 2.55, Ab = 2.605, An = 2.765, and Ne = 2.571 (the last determined on artificial triclinic  $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$ ). The resulting density, 2.685, approximates very closely the measured density, 2.693, and is almost identical with this as corrected for the magnetite inclusions, 2.684. This in itself is a strong proof that the Linosa mineral is a mixed crystal of feldspar and soda anorthite.

This complex mineral would belong logically to the group of feldspars, just as do the barium-bearing members of the orthoclase-celsian series, some intermediate members of which are called hyalophane, and which contain the molecule  $\text{BaAl}_2\text{Si}_2\text{O}_8$ . In this connection it is interesting to note that a sodium-barium plagioclase, described by Des Cloiseaux,\* was crystallographically similar to albite-oligoclase, optically like a labradorite, and with the oxygen ratios of andesine. Mentioning this mineral, Rosenbusch† points out that, as celsian is monoclinic, the barium alumino-silicate must be dimorphous.

The Linosa mineral would thus be a representative of a distinct and hitherto unrecognized triclinic feldspar series, characterized by the joint presence of molecules of albite, lime anorthite, and soda anorthite. Reckoning in with the soda the small amount of potash present, and distinguishing the lime and soda anorthites as Can and Nan respectively, our feldspar would have the composition  $\text{Ab}_x\text{Can}_y\text{Nan}_z$ .

Regarded as a feldspar of such abnormal character, and especially if the assumption is verified that soda anorthite is present and that we are dealing with a representative of a new feldspar series, the Linosa mineral is deserving of a new name. For this we propose *anemousite*, after the ancient Greek name of the island. The term *anemousite* would imply, of course, not only a feldspar with the exact composition given above, but, like hyalophane, oligoclase, labradorite, etc., could be

\* Tscherm. Min. Mitth., p. 99, 1877.

† Mikr. Phys., vol. i, part ii, p. 313, 1905.

applied to feldspars composed of the three molecules mentioned in somewhat varying ratios. If more representatives of the series are discovered, these limits might be more sharply defined, centering round the composition of the present case.

The very close approach to stoichiometric ratios of the oxides may seem to be inconsistent with the view that the mineral is an isomorphous mixture or solid solution. It is, however, in harmony with the well known fact that solid solutions tend to form with their elements in simple ratios, in which case they possess greater stability, giving rise to the substances known as molecular compounds. This is exemplified in many mineral groups, such as the plagioclases, pyroxenes, olivines, nephelite, and the calcite group, the intermediate members of which are very apt to show simple ratios of the end components.

The fact that soda anorthite is not known to occur independently in nature cannot be brought up against the hypothesis of its presence in this case, as the assumption of the presence of a molecule unrepresented by itself in nature is not uncommon in explaining the constitution of many complex mineral groups. Its non-existence as a mineral may be best explained on the ground that the conditions necessary to its formation seldom obtain, the physical conditions being generally such that the more stable nephelite is formed in its stead.

Assuming the presence of the soda-anorthite molecule, it is certainly remarkable that it does not appear to have been detected as yet among the hundreds of chemical analyses which have been made of the feldspars. It would seem to be certain, at least, that it does not enter into the composition of many of these, so far as known, and that, if present at all, it forms only a very small percentage of the feldspar substance, so that its effect in altering the silica ratios would either be overlooked or attributed to impurities or analytical error.

It is a plausible, and indeed reasonable, supposition that we have to do here with a case of imperfect isodimorphism or limited miscibility, as it is termed,\* instances of which have been investigated by Retgers and others. As stated by Groth: "If the temperature intervals for the stability of the individual modifications of two substances differ so widely that, under the conditions ruling during the crystallization, the corresponding state of the one substance is metastable, then as a rule this substance can crystallize along with the other in the form which is stable for it [the other], but only to a limited extent." This is illustrated by monoclinic  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  and

\* Cf. P. Groth, *Introduction to Chemical Crystallography*, New York, 1906, p. 92.

orthorhombic  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ . Monoclinic mixed crystals with the form of the former can be obtained with up to 54 per cent of magnesium sulphate, indicating the existence of a monoclinic form of this salt. Then a gap occurs, until we obtain orthorhombic mixed crystals with 81 to 100 per cent of the magnesium salt, showing the existence of an orthorhombic ferrous sulphate. Very unstable monoclinic crystals of the magnesium salt have been prepared, but orthorhombic ferrous sulphate is as yet unknown in the free state. An analogous case is that of rhombohedral sodium nitrate and orthorhombic silver nitrate. Rhombohedral mixed crystals have been prepared containing up to 52.5 per cent of silver nitrate, while orthorhombic crystals containing only up to 4.5 per cent of sodium nitrate have been obtained. In accordance with these results, no orthorhombic modification of sodium nitrate is known, but the pure rhombohedral silver salt is formed from fusion on cooling.

Analogously we can suppose that  $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$  and  $\text{CaAl}_2\text{Si}_2\text{O}_8$  are isodimorphous, each forming hexagonal and triclinic modifications. Of these, however, only the hexagonal form of the sodium salt and the triclinic form of the calcium salt are stable under ordinary pyrogenetic conditions, while the converse forms are metastable and capable of existence in mixed crystals with the other only in small amount and within a very narrow range of temperature or other physical conditions. The calcium almost always present in nephelite, up to about two per cent, may be thus regarded as existent as hexagonal calcium nephelite,\* which must possess a very limited degree of stability, while the stability of the triclinic modification of the sodium salt is apparently somewhat greater, to judge from the percentage shown by anemousite.

It is obvious that the existence of soda anorthite and its presence in the lime-soda feldspars, or the possibility of the assumption by these of other molecules in solid solution, would have a very important influence on determinative mineralogy and petrography. The optic characters of such an abnormal feldspar would not indicate its true chemical composition in accordance with the tables and diagrams in use at present, as the feldspar would be apparently more sodic than it is in reality. The optic determination of the soda-lime feldspars in thin section would thus not be the comparatively simple and unerring matter that it is now supposed to be, as the possibility of the presence of soda anorthite and its influence on the optic constants would have to be taken into consideration. The recognition of celsian introduces a similar uncertainty.

\* Morozewicz (op. cit., p. 988) and others consider the calcium as replacing the sodium in nephelite.

Again, assuming the possibility of existence of soda anorthite, it would presumably depend on the conditions controlling during crystallization, whether the sodium-alumino orthosilicate would crystallize as nephelite in separate individuals, or as soda anorthite in mixed crystals with albite and anorthite. With identical chemical composition of the rock, we would have in the one case a nephelite tephrite, and in the other a feldspar basalt, but the norms of both would be the same and would show normative nephelite, since nephelite and soda anorthite are normatively the same molecule. We might explain in this way the anomaly of certain holocrystalline rocks containing plagioclase, the norms of which show considerable nephelite, though none of this mineral is present in the mode; and this may be applied to the normatively nephelitic feldspar basalts of Linosa itself. In some cases, of course, the discrepancy is to be attributed to the readjustments of the normative molecules due to the formation of other modal minerals, and the case is mentioned as illustrating some of the petrographic possibilities consequent on the existence of soda anorthite.

The points brought out in the preceding paragraphs indicate the importance and necessity of the verification of the assumed existence of soda anorthite, before any modification is called for of our ideas in regard to the composition and constitution of the soda-lime feldspars, based as these are on the large amount of accurate work by Tschermak, Schuster, Fouqué, Michel Lévy, Fedorow, and others. The very general agreement of the observations of all these workers with the theory that only mixtures of  $\text{NaAlSi}_3\text{O}_8$  (albite) and  $\text{CaAl}_2\text{Si}_2\text{O}_8$  (anorthite) are involved is strong evidence in favor of its general truth, and points to the conclusion that, if present at all, the amount of soda anorthite must be very small in most feldspars so far examined. On the other hand, the occasional very notable divergences from the figures demanded by the premises and the variability of the feldspars optically, indicate the possibility of the presence of some modifying constituents one of which might well be the molecule suggested by us.

#### *The Formation of Soda Anorthite.*

Fouqué and Michel Lévy\* succeeded in 1880 in producing oligoclase, labradorite, and anorthite containing strontium, barium and lead, instead of calcium, but they did not apparently attempt the formation of soda anorthite.

\* *Synthèse des Minéraux et des Roches*, Paris, 1883, p. 145.

The possibility of the existence of this mineral seems to have been first pointed out by Lemberg,\* though he did not succeed in preparing it, and he remarks on its probable instability under ordinary conditions.

Soda anorthite seems to have been actually formed by S. J. Thugutt† by heating artificial “nephelite hydrate” to a white heat, followed by rapid cooling. A crystalline melt was obtained which contained lath-shaped sections of an apparently triclinic mineral, which showed numerous polysynthetic twinning lamellæ, with extinction angles of about  $36^\circ$ . The photomicrographs in Thugutt’s paper show clearly sections of this twinned plagioclase-like substance.

E. Esch‡ describes a nephelite in the nephelinite from the Etinde volcano in German Kamerun. This nephelite shows extraordinary optic properties, and in all probability is triclinic, the crystals being intricately twinned so as to resemble an apparently simple nephelite crystal. The individuals are biaxial, with small optic axial angle, optically negative, and so twinned that basal sections are often divided into sextants, one of which may be normal to a negative acute bisectrix, while the opposite sextant is then about normal to the positive obtuse bisectrix. From this behavior, combined with large extinction angles, Esch considers the mineral to be triclinic.

It may also be noted, as germane to the present subject, that the corresponding potassium alumino-silicate,  $K_2Al_2Si_2O_8$ , has been produced artificially in several modifications which differ crystallographically from the natural mineral kaliophilite.§ One of these, formed by Lemberg and examined by Lagorio, was in aragonite-like twins, resembling those of the Etinde nephelite. Another was isometric, while those formed by Weyberg were prismatic and possibly tetragonal.

In the Geophysical Laboratory, soda anorthite was first obtained in 1905 by Dr. Allen by fusing together the component oxides in proper proportions. The resulting glass was clear and brilliant|| but contained bubbles here and there, and although it softened gradually at high temperatures it was not as viscous as albite glass. The power of crystallization of this substance from the pure melt is not so great as that of many silicates, owing to its high viscosity. The glass was crystallized by heating it to  $1080^\circ$ , and was examined by

\* *Zeitschr. deutsch. geol. Ges.*, vol. xl, p. 641, 1888.

† *Neues Jahrb.*, Beil. Bd. ix, p. 561, 1894.

‡ *Sitzb. Berl. Akad.*, vol. xviii, p. 400, 1891.

§ *Cf. Z. Weyberg, Centralblatt Min. etc.*, p. 395, 1908.

|| For a determination of the refractive indices of this glass, the writers are indebted to Mr. E. S. Larsen, of the Geophysical Laboratory. His values were obtained by the minimum deviation method with a polished prism of the glass. The results were:  $n_{Na} = 1.5181$ ,  $n_{Li} = 1.5148$ ,  $n_{Ti} = 1.5208$ .



Wright at the time. It varied in granularity and, except for occasional patches of more crystalline material, was too fine for optic determinative work. No separate crystals were obtained and no goniometric measurements could therefore be made. Since 1905 repeated experiments have been made with the crystallization of this substance from the melt, and also by heating the glass at different temperatures, but the results of the optic examinations have been practically the same in each case, and the different experiments need not be considered in detail here.

FIG. 1.

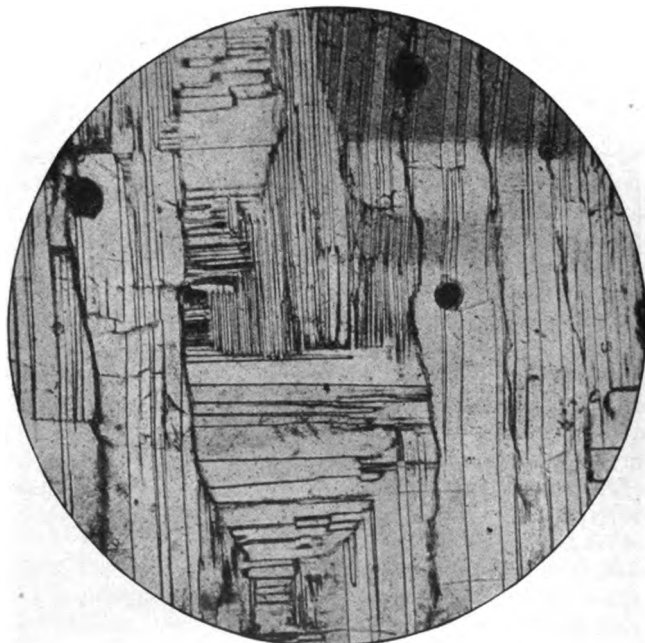


FIG. 1. Polysynthetic albite-like twinning on artificial soda anorthite. Nicols crossed. Magnification 85 diameters.

The most characteristic feature of this form of  $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$  is its polysynthetic twinning, which in many instances closely resembles that of the plagioclases (fig. 1). On other sections the cross grating twinning of microcline is developed, and if encountered in a rock section might easily be mistaken for this (figs. 2 and 3). The extinction angles on such polysynthetically twinned individuals ranged up to  $44^\circ$  on symmetrically extinguishing sections, the angles between the (c) ellipsoidal axes of adjacent lamellæ being  $88^\circ$ . As in the plagioclase

lamellæ, the extinction angles in the zone of symmetry varied with the position of the sections, and the symmetrical extinction angles most commonly observed ranged between  $35^{\circ}$  and  $40^{\circ}$ , the ellipsoidal axis  $c$  being next the twinning junction line in each case.

In many of the sections showing apparently albite twinning lamellæ, a second set of polysynthetic lamellæ often appeared, making usually angles of  $57^{\circ}$  to  $63^{\circ}$  with the first, and so distributed in the lamellæ of the first set as to be symmetrical to

FIG. 2.



FIG. 2. Polysynthetic microcline-like twinning on soda anorthite. Nicols crossed. Mag. 75 diameters.

its planes of twinning. Thus, if the lamellæ of the first set (albite lamellæ) are placed in a north-south direction, then in lamella No. 1 of this set the lamellæ of the second set trend N.  $60^{\circ}$  E. approximately, while in the adjacent lamellæ No. 2 of the first set the lamellæ of the second set trend N.  $60^{\circ}$  W., the N.-S. direction acting as a plane of symmetry. The positions of extinction of the interposed lamellæ in any given twinning band of the first set agree closely with the extinction positions of the immediately adjoining second lamellæ of the first set.

The general tendency of this involved twinning is to produce a hexagonal network of interpenetrating lamellæ, but ordinarily one set predominates and the other sets appear only dimly outlined in the background.

As a result of this complicated twinning, single individual grains suitable for optical work were rarely observed, and were then too small for accurate measurements. Optic axial angle determinations were influenced particularly by this condition, and although much time was spent in searching for suitable

FIG. 3.



FIG. 3. Polysynthetic twinning on artificial soda anorthite. Nicols crossed. Magnification 75 diameters.

sections, the angular values obtained varied considerably. The most probable value for  $2V$  is about  $36^\circ \pm 5^\circ$ . The optic character is negative. The refractive indices were determined by the immersion method:  $\alpha = 1.516 \pm .003$ ,  $\gamma = 1.520 \pm .003$ . The birefringence is weak and was measured on several sections, the highest value for  $\alpha - \gamma$  being 0.0042.

The specific gravity of soda anorthite was determined by the pycnometer method of Day and Allen, and the value 2.571 at  $25^\circ$  was obtained.

Experiments on the melting temperature of soda anorthite have been made, and also on the relation between soda anorthite and nephelite, whether they are monotropic or enantiotropic, but the results are not yet decisive, and mention of them will be deferred until more definite information is at hand.

In one of the preparations crystallized at about  $1100^{\circ}$ , single grains free from twinning were observed, which proved to be uniaxial and optically negative, and similar to nephelite in other properties, except that the refractive indices were very slightly lower. Artificial nephelite has been produced by several workers.\*

The effect of an impurity, or of the presence of other substances, on the stability of soda anorthite has not yet been determined. It is, however, of interest to note that, while soda anorthite crystallizes invariably out of the pure  $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$ , melt, crystals obtained by melting down natural nephelite from Magnet Cove, Arkansas, and then allowing it to crystallize, were uniaxial and optically negative, and agreed in optic properties with the original nephelite. Natural nephelite is not the pure sodium salt, contains but notable but varying amounts of potassium as ever-present and essential constituent, and from its melt not a trace of the triclinic form was observed to crystallize out.

It is to be hoped that eventually well-developed crystals of soda anorthite will be obtained suitable for precise optic and goniometric work, because then its relation to the plagioclase feldspars, whether isomorphous or not, can be positively determined. The fact of its notable solid solution in the Linosa plagioclase, the similarity in twinning phenomena, refractive indices, birefringence, specific gravity, triclinic symmetry relations, and also in the chemical formulas, are strong arguments in favor of close crystallographic resemblance and probable isomorphous relations between soda anorthite and the plagioclase feldspars.

In the preceding pages the name soda anorthite has been applied to the triclinic phase of  $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$ , this having been used previously by Lemberg and Thngutt. While this name has some justification by analogy, and might serve as a provisional designation, yet it is open to serious objections. In the first place it is not in harmony with the usual nomenclature of the feldspars, soda orthoclase, for instance, signifying

\* Fouqué and Michel Levy, C. R., lxxxvii. p. 961, 1878; xc, p. 698, 1880; and Bull. Soc. Min. Fr., ii, p. 116, 1879; and iii, p. 118, 1880; Hautefeuille, Ann. de l'Ecole Monn. Supér., ix, 1880; Bourgeois, Ann. Phys. Chim., 1883, p. 19; Doelter, Zeitschr. Kryst., ix, p. 321, 1884; C. and G. Friedel, Bull. Soc. Min. Fr., xiii, p. 129, 1890.

not a purely sodic monoclinic feldspar, but an orthoclase in which sodium partially replaces potassium. Also if, as is probable, the presence of this  $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$  molecule is verified in other feldspars, the use of the term soda anorthite will be apt to lead to awkwardness and ambiguity. The compound name, furthermore, does not lend itself to the formation of an appropriate symbol, as Ab, An, and Or, for use in feldspar formulas; and finally the new triclinic feldspar, which has been actually formed in a pure state, and which we have shown to be capable of existence in nature in mixed crystals, is of such practical and theoretical importance as to deserve a special and distinctive designation. For these reasons we propose to substitute for the earlier and essentially descriptive term soda anorthite, applied to the triclinic form of  $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$ , the name *Carnegeite* (symbol Cg), in honor of the founder of the Institution under whose auspices the mineral was collected and the present investigations were undertaken.

Locust, New Jersey, and

Geophysical Laboratory of the

Carnegie Institution of Washington, D. C., October, 1909.

ART. VI.—Some Rare and Imperfectly Known Brachiopods from the Mississippian; by DARLING K. GREGER.

THE four species of Brachiopoda which are figured here have caused not a little confusion to collectors of Mississippian fossils, the writer having frequently observed them severally labeled as the *Rhynchonella ringens* of Swallow, in local collections. That the shell described by Prof. Swallow under the name above referred to may be definitely known, and that a distinctive appellation may be had for the forms long confused with it, is the object of the present paper.

*Camarophoria ringens* (Swallow). Figs. 7, 8.

*Rhynchonella ringens* Swallow, 1860, Trans. Acad. Sci. St. L., Vol. II, page 653.

*Original description*.—"Shell large, thick, triangular, plicated, truncated and flattened in front. Ventral valve flattened, triangular; the anterior and the posterior lateral margins abruptly turned up to meet the dorsal valve; the anterior lateral margins curved down in the opposite direction; beak acuminate; sinus wide and shallow, containing about eight plications. Dorsal valve more convex; anterior and posterior lateral margins abruptly turned down to meet the opposite valve; strongly arched towards the anterior lateral margins. The juncture of the valves is sharply and deeply serrated. Surface marked with about fourteen large plications on each valve. Length, 1.90; breadth, 1.48; thickness, 0.99."

The plications all have their origin at or near the beak and increase in size as they approach the front, the number occupying the sinus and fold being quite variable; their number is never increased either by implantation or bifurcation over the body of the shell.

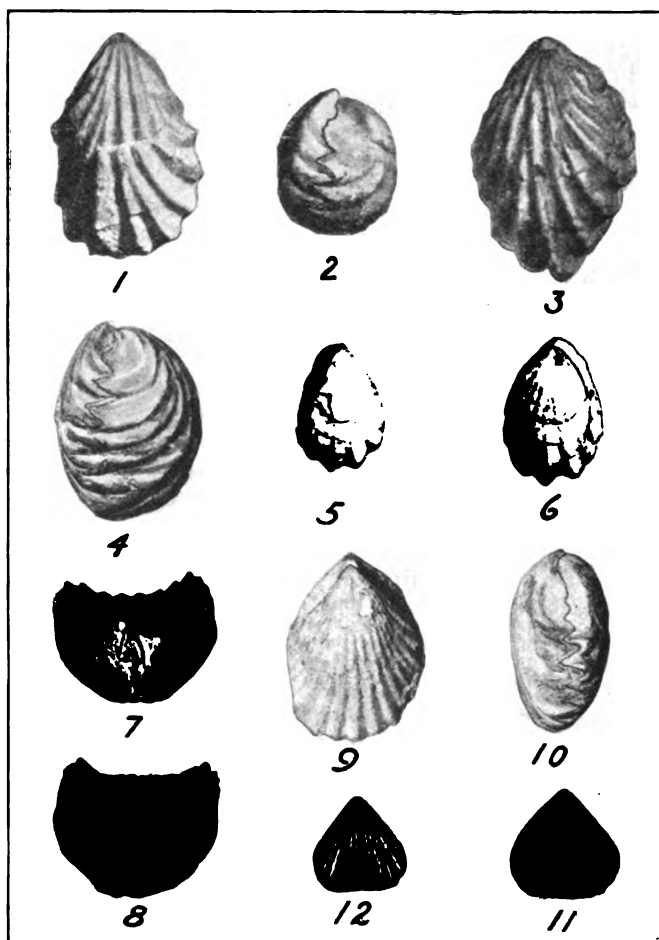
The specimen we figure is from the Boyce collection and bears a label written by the late Prof. Swallow; and while it is not so large as the type, we have no reason to doubt its being the species to which his description applies, since we have collected from the Burlington cherts of Callaway county numerous single valves that equal the dimensions given by the author. Locality and horizon of the figured specimen, and a number of others in our collection—East of New Bloomfield, Callaway county, Mo., in residual cherts of the Burlington limestone.

That the shell figured by Dr. Girty\* from the Madison

\* Monograph U. S. G. S., vol. xxxii, pt. 2, 1899, p. 537, pl. lxix, figs. 1<sup>a</sup>, 1<sup>b</sup>, 1<sup>c</sup>.

limestone is not conspecific with *Camarophoria ringens* is obvious if one follows the description with care, but whether Dr. Girty's shell should be referred to our *Paraphorhynchus*

FIGS. 1-12.



*gibbosum*, or to the species described by Dr. White\* under the name *Rhynchonella caput-testudinis*, we are not in a position to state, nor are we willing to risk the placing of either in the genus *Paraphorhynchus*, since practically nothing is known of their internal structure. However, Dr. White's

\* Proc. Boston Soc. Nat. Hist., 1862, vol. ix, p. 23.

description of the exterior of his shell would suggest a species of *Paraphorhynchus*; he says “\* \* \* surface marked by from sixteen to eighteen distinct somewhat rounded plications on each valve, which mostly reach the beak with some distinctness, but are occasionally increased both by implantation and bifurcation; they are traversed by fine radiating lines and crossed by fine concentric lines of growth.”

*Camarophoria arctirostrata* (Swallow). Figs. 11, 12.

*Rhynchonella arctirostrata* Swallow, 1863, Trans. Acad. Sci. St. L., Vol. II, page 34.

This species was described by Prof. Swallow from material collected at Boonville, Mo., from the Keokuk limestone. The original description reads as follows: “Shell triangular or cuneate, valves nearly equal, costate, striate. Ventral valve most convex towards the beak, which is long, pointed, and strongly incurved. Dorsal valve most convex in front; beak small, pointed, and strongly incurved. Both valves flattened in the middle, and bent abruptly near the margins, forming perpendicular subrectangular faces on the sides and one more or less convex and rounded on the front. Each valve marked with from fourteen to sixteen rounded, radiating, plications, which extend to the beak—two or three implanted—and are ornamented by fine longitudinal striæ, and by obsolete concentric folds. The angle at the beak very variable.”

Our figures are from specimens collected at the type locality and labeled by Prof. Swallow, being a part of the Boyce collection. Average measurements are as follows: length, 15<sup>mm</sup>; breadth, 15<sup>mm</sup>; thickness, 12<sup>mm</sup>.

The general outline of this species at once recalls *Camarophoria subcuneata* Hall, which fact was noticed by Prof. Swallow, but the peculiar, interrupted, hair-like lines on the plications at once removes the possibility of its belonging to Hall's species. Prof. Swallow's statement that the ribs are ornamented by longitudinal striæ is correct only in a sense, since the striæ are not only interrupted but are also inclined to curve down to the interradiar grooves. Sinus and fold obsolete or wanting in this species.

*Paraphorhynchus gibbosum* sp. nov. Figs. 1-6.

*Rhynchonella* sp. Keyes, 1894, Mo. Geol. Surv., Vol. V, pl. xli, figs. 8 a-b.

Shell elongate-ovate, very gibbous, greatest width at or anterior to the median line, fold and sinus obsolete or wanting in most examples. Valves ornamented with a few coarse ribs, irregular in number and position, increased by implantation



and bifurcation, entire surface covered with fine longitudinal striæ, valve margins sharply serrate. Pedicle valve inflated, flattened in the middle, gently curved upwards in the anterior and posterior regions with the postero-lateral margins inflected, beak somewhat prominent and pointed. Brachial valve decidedly more gibbous than the former, beak less prominent and obscured by that of the opposite valve, postero-lateral margins inflected or flattened, corresponding with the opposite valve.

This is one of the very rare brachiopods of the Burlington limestone and well preserved specimens are seldom met with; it is only in specimens retaining the exterior uninjured that the delicate longitudinal striæ are to be observed.

Our collection contains specimens from Louisiana, Mo., and Hannibal, Mo., the last being the locality from which Dr. Keyes obtained his specimens. Figures 1, 3, and 4 are of the largest so far observed, measuring: length, 39<sup>mm</sup>; breadth, 25<sup>mm</sup>; thickness, 28<sup>mm</sup>.

*Paraphorhynchus ovatum* sp. nov. Figs. 9–10.

Shell elongate-ovate, greatest width anterior to the median line, vertically compressed, the transverse diameter always greater than the vertical, fold and sinus obscure, producing only a slight sinuosity in the marginal line. Surface ornamented with eighteen to twenty low rounded ribs, which have their origin near the beak, growing constantly larger as they approach the front; the surface is further ornamented by fine longitudinal striæ, three or four in the space of one millimeter.

Pedicle valve but slightly inflated, sloping gently from the center to the anterior and antero-lateral margins and somewhat more abruptly to the posterior end; postero-lateral margins inflected, beak not prominent, incurved. Brachial valve with less depth than the former, subequally sloping and inflected in the postero-lateral region; beak small and blunt. Average dimensions of the specimens in our collection: 35<sup>mm</sup> long, 27<sup>mm</sup> broad and 16<sup>mm</sup> in thickness, the greatest thickness being in the umbonal region.

Horizon and locality—Chouteau limestone, Kiesenger Bluff, Warsaw, Benton County, Mo.

EXPLANATION OF FIGURES.

*Paraphorhynchus gibbosum* sp. nov.

- FIG. 1. Brachial view of specimen from Hannibal, Mo.
- FIG. 2. Profile view of specimen from Hannibal, Mo.
- FIG. 3. Brachial view of large specimen from Louisiana, Mo.
- FIG. 4. Profile view of specimen from Louisiana, Mo.
- FIG. 5. Brachial view of young specimen from Hannibal, Mo.
- FIG. 6. Brachial view of specimen from Hannibal, Mo.

*Camarophoria ringens* (Swallow).

- FIG. 7. Posterior view of specimen from New Bloomfield, Mo.
- FIG. 8. Anterior view of same.

*Paraphorhynchus ovatum* sp. nov.

- FIG. 9. Brachial view of specimen from Warsaw, Mo.
- FIG. 10. Profile view of specimen from Warsaw, Mo.

*Camarophoria arctirostrata* (Swallow).

- FIG. 11. Brachial view of specimen from type locality, Boonville, Mo.
- FIG. 12. Pedicle view of somewhat smaller specimen from same locality.

Figures  $\frac{1}{2}$  natural size.

Fulton, Missouri.

ART. VII.—*Descriptions of Tertiary Plants, III*; by  
T. D. A. COCKERELL.A *SORBUS* FROM FLORISSANT, CONSIDERED TO BE A HYBRID.*Sorbus diversifolia* (Lx.), fig. 1.*Myrica diversifolia* Lx., Cret. and Tert. Flora (1883), p. 148, pl. xxv, f. 6 (not *Cratægus diversifolia* Steud.; not *Pyrus diversifolia* Bong.).*Cratægus acerifolia* Lx., Cret. and Tert. Flora, p. 198, pl. xxxvi, f. 10 (not *C. acerifolia* Moench).*Cratægus lesquereuxi* Ckll., Bull. Torr. Bot. Club, 33 (1906), p. 311 (not *Sorbus lesquereuxii* Nath.).*Onoclea reducta* Ckll., Bull. Am. Mus. Nat. Hist., 24 (1908), p. 76 and 108, pl. vi, f. 4.

THE extraordinarily variable plant to which the above names have been applied is quite common in the Miocene shales of Florissant, at Station 14. A good leaf was also found by my wife at Station 20. In Knowlton's Catalogue (Bull. U. S. Geol. Surv. No. 152) *Myrica diversifolia* is referred as a synonym to *Cratægus flavescens* Newberry (*newberryi* Ckll.); but in his Fossil Flora of the John Day Basin, p. 66, Dr. Knowlton recognizes that while the John Day specimen referred to *Myrica diversifolia* by Lesquereux is undoubtedly *C. flavescens*, the Florissant specimens are doubtfully identical. There occurs at Florissant (Station 14, *W. P. Cockerell*), a species of *Cratægus* which I have provisionally referred to *C. newberryi*, although the leaf is less deeply lobed, and it is not unlikely that the plant is distinct. This, however, has nothing to do with the true *Myrica diversifolia*, which is evidently identical with *Cratægus lesquereuxi*. A comparison of numerous specimens had convinced me that this well-named "*diversifolia*" was a *Pyrus* in the broad sense, and probably a *Sorbus*; but I possessed no material exactly comparable, although I distinctly remembered having seen a similar living plant. During the past summer I was permitted to gather leaves in Kew Gardens, and there at length I found what I had been looking for, labelled *Pyrus pinnatifida* var. *fastigiata*, and *Pyrus neuillyensis*. These trees are hybrids between the *Aucuparia* and *Aria* sections of *Sorbus*. *P. pinnatifida* Ehrh. is properly called *Sorbus hybrida* Linné. It has the apical half of the leaf like *Sorbus intermedia* Pers. (*Pyrus intermedia* Ehrh.), while the basal half is variably cut into leaflets in the manner of the *Aucuparia* group. This occurs in Europe as a natural hybrid (*intermedia* × *aucuparia*).

There is a variety known as *decurrens* Koehne, in which only three to five of the upper leaflets are connate in a terminal lobe, which, like the separate leaflets, is decurrent at the base. Another variety is *S. hybrida* var. *neuillyensis* (Dippel), (*Pyrus neuillyensis* Hort.), of garden origin, having about four pairs of separate leaflets, those of about the apical third connate, but the leaflets not at all decurrent at the base.

A related hybrid is *Sorbus thuringiaca* (Ilse) = *Pyrus thuringiaca* Ilse, with shorter leaves, as might be expected from the parentage, *S. aucuparia* × *aria*. In the fossils, the characters of these hybrids are reproduced with astonishing exactitude. The more common form is similar to *S. hybrida*,

FIG. 1.

FIG. 2.

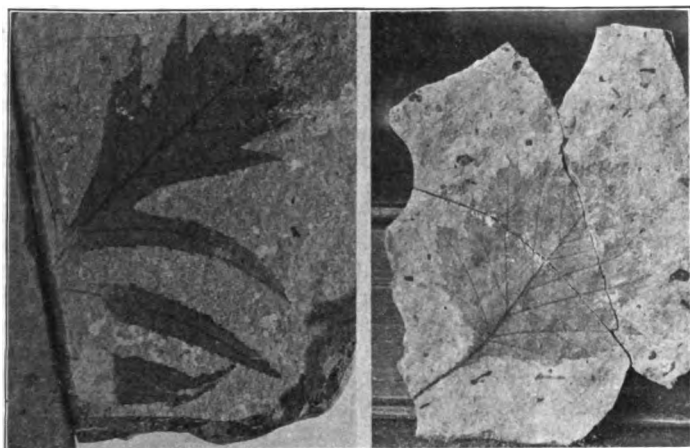


FIG. 1.—*Sorbus diversifolia*.

FIG. 2.—*Sorbus nupta*.

but narrower, and as in var. *decurrens*, the divisions are strongly decurrent at the bases, so much so that the leaflets are not wholly separated. In a form which I collected at Station 14 (fig. 1), the lobing extends far toward the apex of the leaf. The form of the petiole, as well as the structure of the blade, is extremely similar in the fossil and recent leaves. Being thus wholly convinced that *Sorbus diversifolia* is a hybrid, I naturally sought for the parents. It was necessary to find in the shale species of the compound-leaved or *Aucuparia* type, and also the dentate, or slightly lobed *Aria* type. The first has already been published as *Sorbus megaphylla* Ckll., Bull. Am. Mus. Nat. Hist., 1908, p. 95, pl. ix, f. 29. The second, at first regarded as a mere variety of *S. diversifolia*, may be described as follows:

*Sorbus nupta* sp. nov., fig. 2.

Leaf-blade about 67<sup>mm</sup> long, and nearly as broad, with short triangular lobes, the margin also sharply dentate. Structure and appearance of leaf exceedingly like that of the Italian *S. cratægifolia* (Targ.-Tozz.) Wenzig, except that the Italian plant has the base of the leaf strongly cordate, whereas in the fossil it is strongly though narrowly decurrent on the petiole, extending for a distance of at least 10<sup>mm</sup>. The strong lateral veins are five or six pairs, as in *S. cratægifolia*. The sharp teeth are perhaps a little more in the manner of *S. latifolia* Syme (*rotundifolia* Auctt.). There is a strong resemblance to *S. intermedia* in the lobing and toothing, but the shape of the leaf is different.

Florissant, in the Miocene shales, Station 13 B (1908).

*S. diversifolia* is thus considered to be *S. megaphylla* × *nupta*. The only objection to this parentage appears to lie in the fact that *diversifolia* leaves are normally narrower than those of *hybrida*, whereas from the breadth of *S. nupta* one would expect them to be broader.

There is reason to believe that the decurrent base of the leaf is a primitive character; the earliest form of leaf in the *Pyrus* group may perhaps have been narrow-lanceolate, like the living *P. salicifolia* Pall. from the Caucasus, which I had an opportunity of examining in the Cambridge Botanical Garden. From this, *P. amygdaliformis* Vill. (S. Europe) affords a transition to the more ordinary types. The extreme limit of modification is seen in *Sorbus aucuparia* var. *laciniata* (*Pyrus aucuparia* var. *laciniata* Hort. Kew.), in which the leaflets themselves are deeply lobed.

## SCIENTIFIC INTELLIGENCE.

## I. CHEMISTRY AND PHYSICS.

1. *The Relative Volatility of the Bromides of Barium and Radium.*—STOCK and HEYNEMANN have determined the temperatures at which the bromides of calcium, strontium and barium begin to sublime in a quartz tube exhausted by the mercury pump as follows :

Calcium bromide, about	720° C.
Strontium bromide, “	770
Barium bromide, “	820

These results showed that the temperature of sublimation rises with the atomic weight of the metal in these cases, and it was inferred that barium bromide would sublime more readily than radium bromide. This was found to be the case by fractionally subliming several samples of barium bromide containing varying quantities of radium and determining the radium in the products by the electroscopic method. For instance, a sample gave 8.8 per cent of a sublimate containing 0.008 per cent of radium, while the residue, 88.2 per cent, contained 0.015 per cent of radium. In another case 17 per cent of sublimate contained 4.8 per cent of radium, while the 83 per cent of residue contained 6.6 per cent of radium. The authors are of the opinion that fractional sublimation may be of practical use in the preparation of pure radium salts—*Berichte*, xlii, 4088.

H. L. W.

2. *The Action of Light upon Hydrogen Chloride.*—The action of light in causing the combination of hydrogen and chlorine gases is very familiar, hence it is surprising to find from the experiments of COEHN and WASSILJEWA that ultra-violet light is capable of decomposing hydrochloric acid gas to some extent into hydrogen and chlorine gases. These investigators, having previously found a similar decomposition of  $\text{SO}_2$  into  $\text{SO}$ , and  $\text{O}_2$ , passed pure  $\text{HCl}$  gas through a quartz tube, where it was exposed to the light of a quartz-mercury-vapor lamp. The gas was then led through a blackened glass tube into potassium iodide solution where the liberation of iodine indicated the formation of chlorine, and the unabsorbed gas, collected in a eudiometer, was shown to be hydrogen. The decomposition of the hydrogen chloride in this way amounted to 0.25 per cent. No decomposition was obtained when tubes of glass, instead of quartz, were used. Any suspicion that the liberation of chlorine here was due to the presence of atmospheric oxygen, which might give the reaction of the Deacon process,  $4\text{HCl} + \text{O}_2 = 2\text{H}_2\text{O} + 2\text{Cl}_2$ , was shown to be without foundation since hydrogen was shown to be present.—*Berichte*, xlii, 3183.

H. L. W.

3. *The Ratio between Uranium and Radium in Minerals.*—MLLE. GLEDITSCH has studied this question, which is important in

connection with the theory of the production of radium by uranium. Other investigators have concluded that this ratio is practically constant, but she has obtained the following results after making corrections for certain sources of error in her method:

Radium : Uranium	
French autunite, .....	$2.85 \times 10^{-7}$
Joachimsthal pitchblende, .....	$3.58 \times 10^{-7}$
Ceylon thorianite, .....	$4.19 \times 10^{-7}$

While these results show magnitudes of the same order, they do not agree closely, and the author concludes that the determination of the mean life of radium based upon the existence of a constant ratio between the uranium and radium in minerals cannot be considered exact.

It may be observed in regard to this conclusion that the author does not appear to take into consideration the possible removal by solution of a part of the radium from the minerals. H. L. W.

4. *The Action of Radium Emanation upon the Elements of the Carbon Group.*—RAMSAY and USHER, using the emanation produced in about a week from 1.2111g. of metallic radium, have caused this to act upon solutions of silicon, titanium, zirconium, thorium, and lead compounds for periods of about four weeks, with the result that they believe that they have proven the production of carbon by this action. The following table shows the amounts of carbon found per cubic millimeter of emanation :

Solution of	Carbon, mg.
$H_2SiF_6$ , .....	0.518
$Ti(SO_4)_2$ , .....	0.982
$Zr(SO_4)_2$ , { I .....	1.071
{ II .....	0.873
$Th(NO_3)_4$ , { I .....	2.93
{ II .....	0.968
$Pb(ClO_4)_2$ , .....	0.102

The carbon was found in the form of the dioxide, or as a mixture of this with the monoxide. The amount of  $CO_2$  measured amounted in one case to more than  $0.5^{cc}$ . The authors state that mercurous nitrate gave no trace of carbon dioxide or monoxide, and that similar experiments are being performed with the compounds of other elements.

It is probable that the statement in regard to this production of carbon from other elements will be received with much incredulity, because Sir William Ramsay's previous assertion of the production of lithium from copper in a similar manner was not confirmed.—*Berichte*, xlii, 2930. H. L. W.

5. *Quantitative Chemical Analysis*; by CLOWES and COLEMAN. 8vo, pp. 564. Philadelphia, 1909 (P. Blakiston's Son & Co.).—This English book, which is also issued in America, has passed through eight editions, with continual improvement and enlargement, since its first appearance in 1891. It gives an introduction

to the subject by describing the general processes and giving an extensive series of simple gravimetric determinations (here called estimations according to the British custom) suitable for the practice of beginners. The more important methods of volumetric analysis are then taken up. The general quantitative analysis covers a wide range of subjects, largely technical in character; the analysis of ores, metals, alloys, fuels, fertilizers and other products. It takes up also fire assaying, sanitary water analysis, the analysis of milk, butter, alcoholic beverages, sugar, tea, tanning materials, soap, oils, fats and waxes, and technical gas analysis. One section of the book is devoted to ultimate organic analysis and molecular weight determinations. Although some of the topics are necessarily treated rather briefly and incompletely, the book is an excellent one for giving the student practice in nearly all of the usual work of the analytical chemist. The methods are generally well selected and clearly described, but there are naturally some variations between the British practice here given and what may be called the best American practice in analysis. The book has found extensive use as a text-book, and the new edition will doubtless be still more popular.

H. L. W.

6. *Positive Electricity*—Sir J. J. THOMSON asks:—(1) Does a definite unit of positive electricity exist? (2) If so, what is the size of the unit? This paper introduces a discussion upon these questions at the Winnipeg meeting of the British Association and therefore contains matter previously printed. There are, however, some new experiments upon the effect of magnetic fields on positive and negative rays, which led the author to elaborate theories in regard to neutral doublets. He concludes that even at the start from the cathode the "canal strahlen" include a large number of neutral doublets, if indeed they do not wholly consist of them. Much space is given to discussion of the neutral doublets, both in canal strahlen and retrograde rays, which proceed from the cathode toward the anode. It is supposed that these doublets are of the same character from whatever kind of gas they originate. Thomson refers to a former paper in which he showed that if a vessel was exhausted until the pressure was so low that the discharge would not pass, and small quantities of hydrogen, helium, air, oxygen, carbonic acid or argon were introduced so as to raise the pressure sufficiently to produce a discharge, the velocities of the particles were the same for all the gases. The paper closes with description of a method of measuring the effective magnetic field in the magnetic deflection of canal strahlen.—*Phil. Mag.*, Dec. 1909, pp. 821-845.

J. T.

7. *Doppler Effect in Positive Rays in Hydrogen*.—T. ROYDS has studied this effect, both in front and behind the cathode. He believes that the canal rays mostly start from the negative glow, and believes that the commencement of the cathode glow corresponds to the minimum Doppler effect when the cathode is viewed from

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the anode side. After twenty hours exposure with a cathode fall of 2800 volts, he obtained a marked Doppler effect corresponding to the positive rays approaching the cathode. This minimum velocity is not constant for different wave lengths, but is approximately inversely proportional to the square root of the wave length.—*Phil. Mag.*, Dec. 1909, pp. 895-900. J. T.

8. *Magnetic Rotation of Plane of Polarisation in the Ultra-red.*—Many investigations have been undertaken to put Faraday's experiment on a sound theoretical basis. Voigt has placed all such investigations in two classes, and the author of this paper, Ulfilas Meyer, discusses Drude's theories, which are largely based upon the electron theory. He finds that with crystals of fluor spar, sylvin and rock salt, the amount of the turning of the plane of polarization diminishes with increasing wave length. At  $8.85 \mu$  it is less than a minute for a thickness of the crystal of  $1 \text{ cm}$  and a field strength of 10,000 Gauss units. The influence of ions on this turning is very small in comparison to that of the ions. This conclusion is reached from the ground of Drude's view of the electron theory, according to which ultra-red absorption arises from vibrating ions, while ultra-violet is excited by resonance of rotating electrons.—*Ann. der Physik*, No. 132, 1909, pp. 607-630. J. T.

9. *Instantaneous X-ray photography.*—FRIEDRICH DESSAUER states the desirability of shortening the time of exposure to X-rays, and describes a powerful apparatus which he has devised for this purpose. It consists of a very large induction coil, fed by a powerful current which on arising to a proper value is quickly broken by a peculiarly constructed fuse. This fuse is a calibrated piece of wire which is surrounded by a moist covering consisting of a mixture of earths. When the wire heats, the water vapor is formed quickly under pressure and the fuse explodes with violence, breaking the current. The author recommends his method to physicians and has obtained Röntgen cinematographs of the movement of the heart.—*Physikalische Zeitschrift*, Nov. 10, 1909, pp. 859-860. J. T.

10. *Light and Sound*; by WM. S. FRANKLIN and BARRY MACNUTT. Pp. viii, 344. New York, 1909 (The Macmillan Co.).—This volume is a part of a series of elementary texts; practically a revision of Nichols and Franklin's *Elements of Physics*, which it is doubtless designed to replace. The present volume is the third of the new set: *Mechanics* having appeared in 1907, *Electricity and Magnetism* in 1908 and *Heat* being in course of preparation. Improvement is noted in the relegation to an appendix of the more detailed discussion of lens systems, of radiation and the addition of 86 problems as exercises on the several chapters. An excellent discussion of wave motion in general is illustrated by particular waves in water. A total of 143 pages have been added. Much of the additional matter pertains to practical applications, on the importance of which to elementary students the authors express their opinion in the

following words:—"A so called knowledge of elementary science which does not relate to some actual physical condition or thing is superlatively contemptible."

D. A. K.

11. *Direct and Alternating Current Testing*; by FREDERICK BEDELL; assisted by CLARENCE A. PIERCE. Pp. x, 265. New York, 1909 (D. Van Nostrand Co.).—To call this book a laboratory manual of tests on direct and alternating currents, would not be doing it justice. The consideration given to the underlying principles of the experiments, as well as to the significance of the results, places it both in the category of reference and of text books. It is not offered as an exhaustive treatment of the subject but is sufficiently comprehensive to give the student a good working knowledge. It presupposes only the usual college courses in physical and electrical measurements. The subjects of the seven chapters are:—D.C. generators; D.C. motors; synchronous alternators; single phase currents; transformers; polyphase currents; phase changers, potential regulators, etc. Other chapters on A.C. motors and converters are promised in a later edition.

D. A. K.

12. *Elements of Physics*; by HENRY CREW. Revised by FRANKLIN T. JONES. Pp. xiv, 435. New York 1909 (The Macmillan Co.).—This high school text is a revision of Crew's original *Elements of Physics* and embodies much of his more recent *General Physics*. The insides of the covers contain the English and Metric systems of weights and measures, with tables of their equivalents. In the appendix are given 370 questions reproduced from examination papers of various high schools throughout the country. Definitions and leading statements are emphasised by bold-faced type, and numerous problems are embodied in the text. It is to be hoped that in the next edition the authors may eliminate such slips as "knots per hr.," "attraction of gravity, g," "in physics rate always means 'divided by time'," and revise the somewhat misleading discussion of harmonic motion.

D. A. K.

## II. GEOLOGY

1. *Radio-activity and Geology. An account of the influence of radio-active energy on terrestrial history*; by J. JOLY. Pp. 287. London, 1909 (Archibald Constable & Co., Ltd.).—This book is an outgrowth of the author's presidential address to Section C of the British Association and brings into one volume the present information regarding radio-activity in its bearings on geology. Geologists will consequently find it a most welcome volume since but few have the time or opportunity to follow in the physical journals the rapidly accumulating results of recent investigations.

The first larger subject treated is that of radium in the earth's surface materials. Many measurements have now been made on

igneous and sedimentary rocks. The amount of radium varies, however, within wide limits, the abyssal radiolarian ooze and red clay being especially high. As radium loses half its mass in 1760 years while its ultimate parent uranium takes five billion years for the same loss, it is seen that the radium in the rocks is really a measure of the contained uranium. Strutt, extending the work of Rutherford, has shown that the radio-active materials in the crust exist in sufficient abundance so that a crustal layer less than 100 miles in thickness would continually supply the quantity of heat which the earth loses to space (45 miles in the original estimate). Joly argues, therefore, that the uranium must be concentrated in the outer crust of the earth. Consequently where this concentrated zone is depressed by the accumulating sediments of a geosyncline, the loss by conduction being lessened, the temperature must rise. Local excesses as in the Simplon tunnel are also thought to play an important part in determining local temperature gradients. Joly further argues that the instability of the earth's crust and the ocean floor are also due chiefly to uranium and radium becoming more deeply buried.

Another chapter of great geological interest is that on uranium and the age of the earth. Considering helium and lead as the ultimate disintegration products of uranium, measurements of their amounts in uranium minerals, while varying among themselves and pointing to the need of further research, agree in giving much larger values to geological time than estimates based upon denudation and sedimentation.

Throughout the volume, the author, while arguing for the large influence of radio-activity, shows a spirit of fairness and caution. But there is room for so many possibilities in the underearth, which he does not discuss, that a large degree of skepticism may be maintained toward many of his conclusions. Of the geological importance of radio-activity there can be no doubt and it seems adequate to more than account for the temperature gradient, so that instead of a cooling earth we may come to face the possibility of a heating earth. But the deep-seated distributions of energy, pressure and mass traceable to earth origin, whatever that may be, seem able to play the chief part in terrestrial dynamics without invoking the radio-activity of the outer crust as a controlling cause. The contributions of various writers, but more notably Chamberlin, show the weakness of the outer zone to generate compressive movements, which seem, on the contrary, to be initiated by shrinkage of the centrosphere, periodically producing collapse of a thick outer shell of the earth. The great vertical movements, on the other hand, as shown by investigations on isostasy, seem to be in their origin largely independent of denudation and sedimentation, but dependent upon differential volume changes in the outer hundred miles. The isostatic adjustments are further without doubt modified by surface unloading and loading. These considerations are not adequately discussed by Joly.

To make the foregoing criticisms specific by citing an illustrative point: it is inferred by Joly that uranium is concentrated in the outer hundred miles of the crust because if it extended indefinitely downward in the same amount, the energy liberated would be more than sufficient to maintain the temperature gradient. This inference, however, has no supporting evidence and leads in turn to some assumption as to the manner in which uranium could be so concentrated and yet remain in its extremely diffused state. On this inference of the subsurface concentration is nevertheless based an explanation of the making of mountains and of continental and oceanic movements. As other allowable inferences which would meet the same condition of a subsurface excess in radio-activity, it may be suggested that in the deep body of the earth the pressures and temperatures, greater than any attainable in the laboratory, may partially or completely inhibit the radio-active degradation of uranium, or offsetting heat-absorbing reactions in other materials may take place, or igneous activity may serve as a safety valve to reduce the excess of internal energy transmuted from subatomic to atomic form. These are all speculations which have not been disproved. None of them may be true, but they indicate the danger of arriving at conclusions supported on a complicated superstructure of reasoning when the stability of the foundation premises is open to serious question. In considering the problems connected with internal terrestrial activities the field of the unknown is so large that the method of multiple working hypotheses should be more largely employed than is done in this volume. Nevertheless much is brought out which is stimulating and suggestive. J. B.

2. *The Geology and Ore Deposits of Goldfield, Nevada*; by F. L. RANSOME. U. S. G. S., Prof. Paper No. 66, pp. 253, 35 plates, 34 text fig. Washington, 1909.—The Goldfield district consists essentially of a low, domical uplift of Tertiary lavas and lake sediments resting upon a foundation of ancient granite and metamorphic rocks. The erosion of this flat dome has exposed the pre-Tertiary rocks at a number of places in the central part of the district, and these outcrops are surrounded by wide concentric zones of successively younger formations. Some of the later lavas were erupted after the dome had been elevated and truncated. The pre-Tertiary rocks consist to-day of quartz rocks intruded by masses of a granitic rock like that to which the name alaskite has been given. The Tertiary lavas include dolerite, rhyolite, basalt, andesite and latite. Most of these are found in different flows of different periods and lying between them are various fragmental rocks.

The sulphide ores of the Goldfield district are of complex mineralogical character, native gold and pyrite being accompanied by minerals containing copper, silver, antimony, arsenic, bismuth, tellurium, and other elements. In some ores the gold occurs free in fine particles, which, as a rule, are aggregated together to form yellow bands or blotches. The associated minerals are pyrite,

marcasite, bismuthinite, perhaps famatinite, and a new cupric sulphantimonite, which has been named goldfieldite. (See below.)

The most notable features of these ore bodies are their remarkable richness and their equally remarkable irregularity. The ores are associated with craggy outcrops of silicified volcanic rock. Associated with the silicification other processes of locally intense alteration, especially the formation of alunite, have also been active. The deposits have formed along irregular and branching zones of fissuring. The surface ores were oxidized and furnished a large part of the gold during the first years of exploitation.

GOLDFIELDITE occurs as a gray material in a dark telluric crust found at the Mohawk mine. The material was crushed and picked over under a lens. The gray portion appeared homogeneous, with the exception of a few minute specks of gold. Color, dark lead-gray, with a high metallic luster. Brittle. Conchoidal fracture. Hardness = 3 — 3.5. No crystal faces noted. Analysis by Palmer on small amount of material gave :

Cu	S	Te	Sb	As	Bi	Au	Ag	Gangue
33.49	21.54	17.00	19.26	0.68	6.91	0.51	0.18	2.00 = 101.57

The mineral is considered to be a cupric sulphantimonite, in which part of the antimony is replaced by arsenic and bismuth and part of the sulphur by tellurium. Formula derived is  $5\text{CuS} \cdot (\text{Sb}, \text{Bi}, \text{As})_4 (\text{S}, \text{Te})_4$ .

It would seem, in view of the facts presented concerning this substance, that the giving to the material a name and rank as a new species is hardly warranted. The material was intimately mingled with other minerals and had to be crushed and picked over by hand, so that the purity of the material analyzed must be somewhat questioned. It showed no crystal forms. The analysis was made on a small amount of material, and shows a high summation, and the formula derived is only approximately justified by the analysis. It would seem desirable that more positive proof should be given before we can assume the existence of such an unusual compound as a cupric sulphantimonite.

W. E. F.

3. *United States Geological Survey ; Issue of Geologic Folios in pocket form.*—The Geological Survey has recently inaugurated the publication of an edition of the Folios of the Geologic Atlas of the United States in octavo form convenient for field use. The maps are folded and enclosed in a pocket so that the whole, including the accompanying text, forms a pamphlet of about 6 x 9 inches. The folio form will also be continued, as it is most satisfactory for office and library use, but the new pocket edition will be welcomed by those at work in the field. The Folio now received is No. 167 of the series, and describes the Trenton, New Jersey-Pennsylvania Quadrangle ; it is stated that the five folios, No. 164–168, have been printed and are ready for distribution in this new form. It is also to be noted that henceforth the separate maps, unfolded, showing the areal geology of the

Quadrangle, will be, when desired, furnished separately at the nominal cost of five cents each.

4. *Geological Survey of West Australia*.—The following publications have recently been received :

Annual Progress Report for the year 1908. Pp. 19, 3 maps.

Bulletin No. 32, containing: Greenbushes Tinfield, by A. Gibb Maitland, A. Montgomery, W. D. Campbell, and Mr. E. S. Simpson. Pp. 75, 2 maps, 2 plates, and 7 photos. Mount Malcolm Copper Mine, by Harry P. Woodward. Pp. 8, 1 plate. Fraser's Gold Mine, Southern Cross, by Harry P. Woodward. Pp. 6, 1 map, 1 plate.

Bulletin No. 35, containing Geological Report upon the Gold and Copper Deposits of the Phillips River Goldfield, by Harry P. Woodward. Pp. 104, 2 maps, 8 plates, 7 photos.

Phosphate deposits have been discovered near Christmas Island, where a layer of phosphatic travertine 153,600 square yards in area and with a thickness of two feet has been investigated. The travertine is believed to owe its origin to capillary attraction, drawing up ground water from the lime contained in the underlying sands. In an investigation of the Green Bushes Tinfield (Bulletin 32) examination was necessarily made of the laterite of this region, which has a wide distribution and varies in composition from solid and pure limonite to aluminous rocks almost destitute of iron and often so tough that explosives have little effect. The distribution and character of the laterite in the Green Bushes region "clearly indicates periodic and zonal changes in the climatic conditions." In connection with the petrographic description of the crystalline rocks of the Phillips River (Bulletin 35) analyses were made of the following types: soda-granite, spodumene, albite, and eclogite.

H. E. G.

5. *Contribuzioni allo Studio Petrographico della Colonia Eritrea*; by E. MANASSE. 4°, pp. 168, 8 plates and map. Siena, 1909.—This work is based upon the collection of rocks made by Profs. G. Dainelli and O. Marinelli during their geological researches in the Italian colony of Erythrea, East Africa, in 1905–1906. After a brief sketch of the geology of the area visited, the main body of the work is devoted to a detailed report of the results of a thorough petrographical study of the specimens. The author first describes, rather briefly, a series of schists of various kinds, including some porphyroid, mica schists, amphibolites, gneisses, etc. Then the igneous rocks are treated, and these were found to consist of granites, some of which, as shown by the analyses, are of alkalic character with predominant soda; diorites of several types; a hornblendite which is a local facies of diorite, and two specimens of teschenite. There are also dike rocks, granite and diorite porphyries, aplites, paisanite, bostonite, tinguaita, malchites and among the lamprophyres, kersantites and camptonites. The effusive rocks or lavas are also not wanting and include quartz porphyry, rhyolite and rhyolitic tuffs, obsidians and pumices. Dacite and a great variety of

basalts close the list. In the sedimentary rocks are found sandstones, argillites, limestones, travertine, etc. The work closes with a chapter dealing with various generalizations on the results obtained. It is illustrated by a large number of excellent photogravures made from microphotographs of the thin sections studied. Its value is also much enhanced by a large number of excellent chemical analyses of the various rocks, which are the result of much patient labor in the laboratory.

The work is an excellent contribution to our knowledge of East African petrology, and it is interesting to observe that the nature of the rocks is in harmony with the general alkalic character of the East African petrological province, as shown by a number of investigators during the last few years.

L. V. P.

6. *Carboniferous Air-breathing Vertebrates of the United States National Museum*; by ROY L. MOODIE. Proc. U. S. Nat. Mus., vol. 37, pp. 11-28, with pls. 4-10.—This paper, the fifth of Dr. Moodie's contributions to our knowledge of the early Amphibia, is a result of the study of a small collection in the National Museum; but one which is of great interest in that it contains the only known examples of scaled Amphibia from North America, as well as the only known specimen of a Carboniferous reptile from the Allegheny series. This reptile, *Isodectes punctulatus* Cope, Doctor Moodie thinks, shows certain aquatic as well as terrestrial adaptations; the former being the broad-surfaced foot, such as MacGregor has described in *Mesosaurus brasiliensis*. The affinities of *Isodectes* are close to the Microsauria among the Amphibia; to what group of reptiles it is related is not known.

Of the Microsauria, Moodie describes some 17 species and 15 genera, of which 3 of the former and 1 of the latter are new. The material comes in part from Linton, Ohio, and Cannelton, Pennsylvania.

R. S. L.

7. *Cenozoic Mammal horizons of Western North America*, by HENRY FAIRFIELD OSBORN; with *Faunal Lists of the Tertiary of the West*, by WILLIAM DILLER MATTHEW. Bull. U. S. Geol. Survey No. 361, 1909, pp. 1-138, with 15 text figs. and 3 plates.—For the student of faunal paleontology as well as the stratigraphical geologist this paper is of the utmost importance, containing as it does a bibliography, a general discussion of the geologic and climatic history of the Tertiary, a careful description of the successive faunal phases, and most comprehensive faunal lists of the Tertiary mammals.

The principal facts established are the two great natural divisions of geologic deposition and of habitat, the mountains and the plains; the progressive aridity of the climate during the Cenozoic with its consequent soil denudation and deforestation, and the destruction of most of the larger forms of life during the lower Pleistocene glacial epoch. The contrast of the mountain and plains regions are no less striking than their resemblances. In the mountain region, with some exceptions, the drainage systems are the same to-day as in the Tertiary, while on the plains

the rivers are comparatively modern. In the mountains from the Basal Eocene to the John Day the rocks are not worked over, as erosion was retarded by the heavy cappings of lava in the John Day basin of Oregon, in the Bridger basin by a dense Pleistocene (?) conglomerate and in the Washakie by a fine conglomerate.

In the plains region, by contrast, the very extensive Oligocene strata were in part worked over to form the Miocene and these in turn to form the Pliocene; all three contributed to the Pleistocene, and all four are now contributing to the alluvium of the Great Plains.

The successive faunal phases are :—

1, Archaic Mesozoic mammals with partly South American, partly European affinities. Basal Eocene.

2, The first modernization, invasion of the archaic by the modern fauna—whence is not surely known, but Osborn favors a North American-Asiatic or Holarctic origin; the severance of the South American land connection—Initial elimination of the archaic fauna in competition with the modern. Wasatch.

3, Absence of fresh Eurasiatic migration, descendants of archaic and modern mammals slowly evolving and competing, with the gradual elimination of the archaic. Establishment of the North American Artiodactyla. Wind River to close of Mocene.

4, Second modernization—First knowledge of the plains fauna—Absence of all archaic mammalia except the Hyænodontidæ—Reestablishment of faunal resemblances with western Europe. Oligocene and Lower Miocene.

5, Fresh migrations from Europe. First proboscidiæ and true Felinæ. Middle Miocene to Lower Pliocene.

6, Land connection with South America. Intermigration of North and South American mammals. Middle and Upper Pliocene.

7 Increasing cold, moisture and forestation. Third modernization by Eurasiatic invasion—Gradual extinction of larger Ungulata. Pleistocene.

Conclusion :—North America promises to give us a nearly complete and unbroken history of the Tertiary in certain regions, which are, after all, comparatively restricted. Middle and Upper Eocene are approaching solution; Lower and Basal Eocene still require additional surveys. The chief remaining gap is now in the Pliocene stratigraphy, materials being at hand for an establishment of the Pleistocene sequence.

R. S. L.

8. *New Fossil Mammals from the Fayûm Oligocene, Egypt*; by HENRY FAIRFIELD OSBORN. Bull. Amer. Mus. Nat. Hist., vol. xxiv, 1908, pp. 265–272, with 6 text figures.

*New Carnivorous Mammals from the Fayûm Oligocene, Egypt*; by H. F. OSBORN. Ibid., vol. xxvi, 1909, pp. 415–424 and 9 text figures.—In these two papers Professor Osborn describes part of the remarkable wealth of material collected in the Fayûm by the expedition from the American Museum sent out during the winter of 1906–1907. The first paper contains descrip-



tions of two new genera of uncertain ordinal position as well as two new genera of rodents, including in all an equal number of species. In the second paper a number of creodont genera and species are described, all referable to the Hyænodontidæ, the last surviving family of the order.

R. S. L.

9. *New or little known Titanotheres from the Eocene and the Oligocene*; by HENRY FAIRFIELD OSBORN, Bull. Amer. Mus. Nat. Hist., vol. xxiv, 1908, pp. 599-617 with 21 figures in the text.

"In the preparation of the U. S. Geological Survey monograph 'The Titanotheres' the collections of Eocene and Oligocene materials in the larger museums of the country have been reviewed with care. Like the Oligocene titanotheres previously reviewed, the Eocene titanotheres prove to be in a high degree polyphyletic." From the Wind River formation are two genera and three species; from the Lower Bridger one genus and three species; from the Upper Bridger and Lower Washakie three genera and five species; from the Upper Washakie and Lower Uinta two genera and four species; from the Upper Uinta two genera and three species, and finally from the White River Oligocene two new genera, each with a single species, are described.

*Dolichorhinus hyognathus*, of which the more familiar name, *Telmatotherium cornutum*, is a synonym, is restored in the skeleton and gives a good idea of the appearance of one of these ancestral titanotheres.

R. S. L.

### III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *The Autobiography of Nathaniel Southgate Shaler*, with a supplementary Memoir by his wife. Pp. 481, with 16 illustrations. Boston and New York, 1909 (The Houghton Mifflin Company).—The six or seven thousand students who heard Shaler's lectures at Harvard during his forty years service were always deeply impressed with his personality, his wide experience of men and the world, and his vivid presentation of the principles of geology, enlivened by ever-flowing narrative of pertinent incidents, all the more entertaining from being phrased in picturesque language. The personality of the man is strikingly presented in this volume, of which the first half, descriptive of his youth up to the beginning of the Civil War, comes from Shaler's own pencil—for it was his habit to prepare manuscript with pencil rather than with pen—while the second half, descriptive of his more mature years, is written by his wife. The picture that we gain of the way in which science was studied at Harvard under Agassiz is particularly interesting; a way that was well fitted for youths of the strong individuality that Shaler possessed. Several chapters on excursions along the coast of Maine and farther down east, with Hyatt, Stimpson, Verrill and others, are of special interest as

illustrating the delightfully primitive conditions of scientific exploration in the early sixties; they show the richness of happenings even on a near-by coast, if one only has the knack of meeting them as Shaler always had.

The memoir by Mrs. Shaler exhibits the extraordinary variety of relations into which Shaler entered after his return to Harvard at the close of the war. It includes accounts of his several journeys abroad, where he made personal acquaintance with the leading geologists of the time; of his work on the Kentucky State Geological Survey and on the Coast Survey; of his occasional westward journeys chiefly in connection with mining interests; of his wide excursions in literary fields, reflected again in the list of publications at the end of the volume; and above all of the innumerable activities at Harvard which made him, as William James put it, "the myriad-minded and multiple-personalities embodiment of all academic and extra-academic *Kenntnisse* and *Gemüthsbewegungen*." The real worth of this book lies in the deep impression that it gives of the value of personality as compared to mere learning.

W. M. D.

2. *Third Report of the Wellcome Research Laboratories at the Gordon Memorial College, Khartoum*; ANDREW BALFOUR, Director. Published for the Department of Education, Sudan Government, Khartoum. Pp. 477, with 28 colored plates, 413 reproductions of drawings and photographs, and 19 maps and plans. London, 1908 (Baillière, Tindall & Cox); New York (Toga Publishing Co., 45 Lafayette St.).—This handsome volume shows the latest work of the enthusiastic investigators at this now famous tropical laboratory. As in the earlier reports, noticed in this Journal, the work covers a wide field of investigation, although such biological topics as concern the health of the natives are given a prominent position.

The blood parasites of man, domestic animals, rats, birds, reptiles, and fishes of the region have been subjected to extensive investigations by the director of the laboratory, and by Dr. Wenyon, both of whom contribute several beautifully illustrated reports, which form important contributions to the knowledge of these important parasites. The sanitary conditions existing in Khartoum are discussed, and further observations on sleeping sickness, kala-azar, and other diseases reported. Poisonous snakes and other reptiles have been studied by specialists, the parasitic worms investigated, and the insects of economic importance discussed and illustrated by colored plates.

The later chapters deal with well illustrated articles on the healing art as practiced by the dervishes, the physical characters of certain negroid tribes, and notes on ethnographical specimens, while the reports of chemical investigations at the laboratory conclude the work. The floating laboratory on the Jurriver has proved a marked success.

The admirable courage shown by those who have made these investigations, under the most trying climatic conditions, has been

further tested by a recent fire which destroyed many of the important preparations and documents at the laboratory. W. R. C.

3. *Illustrations of African Blood-sucking Flies other than Mosquitoes and Tsetse-flies*; by ERNEST EDWARD AUSTIN. Pp. xv, 221, with 13 colored plates. London, 1909 (British Museum of Natural History).—Since the discovery that many of the most fatal diseases of man and animals are disseminated by means of the bites of blood-sucking flies, the British Museum has published a number of handsomely illustrated monographs on various groups of these insects. Belonging to this series is the present volume, which gives general and non-technical descriptions and excellent colored figures of 103 African species, all of which have blood-sucking habits, although it is not yet known which of them may serve in spreading diseases. W. R. C.

4. *The Cambridge Natural History*; edited by HARMER and SHIPLEY. Vol. IV. Crustacea and Arachnida. Pp. xviii, 566, with 286 figures. London 1909 (Macmillan & Co.).—The series of ten volumes of excellent treatises by specialists in the different groups of the animal kingdom is now complete, and forms perhaps the most convenient and generally useful work of reference on the subject that has appeared in the English language in recent years.

The present volume is quite up to the high standard of the others of the series, and treats of the Crustacea, and the widely divergent forms, as king crabs, spiders, scorpions, ticks, mites, water-bears, pycnogonids, and other animals, both fossil and living, which are now generally grouped together as Arachnida. The contributors for this volume are Geoffrey Smith, Henry Woods, A. E. Shipley, Cecil Warburton and D'Arcy W. Thompson. The general excellence of the text is shared by the numerous illustrations. W. R. C.

5. *The Human Body and Health: An Intermediate Text-Book of Essential Physiology, Applied Hygiene, and Practical Sanitation for Schools*; by ALVIN DAVISON. Pp. 223, with 150 illustrations. New York, 1909 (American Book Company).—The aim of this little book is to give the pupil in the public school a general knowledge of the principles of personal and public hygiene. Such of the essentials of the anatomy and physiology of the human body as it is necessary to introduce are clearly described and illustrated. W. R. C.

6. *International Congress of Radiology and Electricity*.—It is announced that an International Congress of Radiology and Electricity will be held in Brussels in 1910 under the patronage of the Belgian government and of the French Physical Society. A provisional program has been issued; the address of the General Secretary is 1 Rue de la Prévôté, Brussels.

## New Circulars.

- 84: Eighth Mineral List:** A descriptive list of new arrivals, rare and showy minerals.
- 85: Minerals for Sale by Weight:** Price list of minerals for blowpipe and laboratory work.
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- Catalogue 26: Biological Supplies:** New illustrated price list of material for dissection; study and display specimens; special dissections; models, etc. *Sixth edition.*

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WITH PLATE I.

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1910.

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# BRIEF ANNOUNCEMENTS.

Recent pressure of business has hindered me from compiling a detailed list of new minerals arrived. I wish to mention, however, a new lot of the metallic Awaruite from Smith River, California, ranging in sizes from  $\frac{1}{4}$  inch to 1 inch. These interesting metallic pebbles are of scientific value on account of the nickel being associated with the iron in the metallic state. Considering the great amount of attrition which they received from stream action, I find them very well preserved and deserving a place in every collector's cabinet. These range in price from 25 cents to \$2.00.

Although the finest of the recent Iceland Zeolites and Franklin Furnace minerals have been sold off rapidly, I still have choice examples of these splendid specimens at reasonable prices.

Having received some excellent shipments representing chiefly Hungary, Saxony and other celebrated German localities, of which specimens I was unable to prepare a list in time for this issue, I shall be pleased to furnish further data on request. I noted in these shipments several specimens of the rare Argyrodite and other silver minerals too numerous to mention.

---

I recently received additional minerals from Colorado and can now supply any reasonable demand in Tellurides, native Tellurium, Amethystin-Quartz, Calciovolborthite and Carnotites. Prices on request.

I have also considerably increased my stock of the celebrated California Tourmalines so that I now feel that no dealer has ever had the quality and quantity of these specimens that I have, while the prices of same have been somewhat lowered, considering their value, as compared with former prices.

Have also made a recent addition to my stock of the Reconstructed Rubies, Sapphires and Pink Topaz, which places me in the best position for supplying the demands of my customers.

It would be advisable for those interested in the above to have their names on my mailing list, and I shall be pleased to send on approval for inspection and selection anything that may interest my patrons.

Information as to special lists and prices of individual specimens cheerfully given.

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T H E

# AMERICAN JOURNAL OF SCIENCE

[ F O U R T H   S E R I E S . ]

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**ART. VIII.**—*The Nitrogen Thermometer from Zinc to Palladium*; by ARTHUR L. DAY and ROBERT B. SOSMAN; with an Investigation of the Metals, by EUGENE T. ALLEN.

CONTENTS :

1. Introduction and Plan.
2. Apparatus.
3. Details, Errors, and Corrections.
  - A. Temperature of Gas in Bulb.
  - B. Definition of Temperature by Measurement of Pressure.
  - C. Transference of Temperature by the Thermoelement.
  - D. The Fixed Points.
4. Experimental Data and Calculated Results.
  - A. Expansion Coefficient.
  - B. Gas Thermometer Data and Fixed Points.
5. Interpolation between the Fixed Points.
6. Analysis of Metals. (By E. T. Allen.)
7. Conclusion.

1. *Introduction and Plan.*

THE measurements of absolute temperature here offered were undertaken in direct continuation of those published from the Geophysical Laboratory two years ago,\* with the purpose of extending the gas scale to 1600°, or as near it as might prove practicable. Except in explanations of new or particularly important features, descriptive details have accordingly been omitted here and must be sought in the first paper. Substantially the same methods and apparatus have been employed throughout.

One conclusion in particular which was brought out at that time is entitled to even greater emphasis, namely, that the existing uncertainties in the absolute temperature scale at 1000° and above are the result of experimental limitations and not of any failure of the principles involved. The experimental conditions were scrutinized with great care throughout the first investigation, and not only were the known correction factors all redetermined, but their total magnitude was reduced nearly 75 per cent. This success, after so long and painstaking

\* Arthur L. Day and J. K. Clement, this Journal (4), xxvi, 405-463, 1908.



ing a study of the correction factors, led the authors to believe that the upper end of the existing gas scale (melting point of pure copper), which has been vacillating in a somewhat irregular way in various hands for three-quarters of a century, had been finally confined to the limits  $\pm 0.5^\circ$ , or within  $1^\circ$ . Although this ideal had been affectionately cherished for a good many years, its triumph has been shortlived. The present investigation has discovered a source of error which appears to have passed unnoticed before, which operates to raise the temperature scale at the copper point about  $1.4^\circ$ . This kind of history has repeated itself with remarkable persistence all through the record of high temperature research, and may, of course, do so again, but the limits of uncertainty are continually becoming narrower, and it appears to the authors unlikely that further investigation will again reveal errors aggregating  $1^\circ$ .

On the other hand, the detailed study of temperature distribution about the bulb (page 102) in which the present error was discovered, cannot but convince an experienced observer that the limit of refinement in an electrically heated air bath has been practically attained, and that higher accuracy in gas thermometry must be sought in a liquid bath which can be stirred.

Since the publication of the Reichsanstalt scale\* in 1900, it has remained the standard for all temperature measurements between  $400^\circ$  and  $1100^\circ$ . Its limit of accuracy as an absolute scale was estimated to be about  $3^\circ$  at  $1000^\circ$ .

The work of Day and Clement was mainly directed to the following essential features of the problem of absolute measurement with a constant volume gas thermometer: (1) An absolutely gas-tight bulb of definite volume; (2) uniform distribution of temperature over the bulb surface during the measurements; (3) the reduction of the error due to the unheated capillary tube connecting the bulb with the manometer; (4) a more accurate determination of the expansion coefficient of the bulb itself.

The results accomplished by them in these directions may be outlined seriatim as follows: (1) The bulb chosen (90 parts platinum, 10 parts iridium) is quite rugged enough for measurements as high as  $1500^\circ$ , and no difficulty was experienced in maintaining a nitrogen atmosphere in it without loss by diffusion or leakage. At high temperatures the material becomes considerably softer, but with the help of a gas-tight furnace in which nitrogen could be maintained at the same pressure outside the bulb as within, neither diffusion through the bulb walls nor mechanical strain was encountered. Variations in the zero point of the thermometer, which have been

\* L. Holborn and A. L. Day, *Ann. d. Phys.* (4), ii, 505, 1900; *this Journal*, (4), x, 171, 1900.

very persistent and inaccessible errors throughout the history of gas thermometry, have therefore now become practically negligible. This gas-tight furnace possessed the further advantage that the initial pressure of the gas, and consequently the sensitiveness of the instrument, could be varied within considerable limits. A sensitiveness as great as  $1^{\text{mm}}$  of the manometer scale per degree was regularly employed. The iridium alloy has the disadvantage that platinum thermoelements, which are necessary for recording variations in the temperature over the surface of the bulb, and for transferring the gas thermometer temperatures to standard melting points, become contaminated in the presence of iridium at all temperatures above  $900^{\circ}\text{C}.$ ; the higher the temperature and the longer the time of exposure, the greater the degree of contamination.

(2) It was sought to obtain a uniform temperature over the surface of the bulb by winding the (pure platinum) furnace coil on the inside of a refractory magnesia tube which contained sufficient iron oxide and other impurities to be a fairly good conductor of heat. The winding was somewhat closer at the ends than in the middle. This was further supplemented by secondary coils of smaller wire extending a few centimeters into the tube from each end. The current in the three coils could be independently regulated with the help of thermoelements attached to the bulb and giving its temperature at the middle and upon each shoulder (positions 2, 4, and 6, fig. 1). When these temperatures had been adjusted so that the differences between them were smaller than  $0.5^{\circ}$ , it was assumed that the temperature over the whole surface of the bulb was constant within those limits. (For the oversight in this assumption, see pages 99 and 102.)

(3) The platinum capillary and connections between the bulb and the manometer were much diminished in volume. Compared with the total volume of the bulb ( $195.7^{\text{cc}}$ ) this connecting volume amounted to  $.0015$  in their instrument, and reduced the total correction for the "unheated space" to less than  $5^{\circ}$  at  $1100^{\circ}$ , a correction factor not more than one-fourth as large as the best previous attainment in this direction. The uncertainty of the temperature distribution in the "unheated space" was perhaps 10 per cent, making the probable error from this source about  $0.50^{\circ}$ .

(4) A special bar  $25^{\text{cm}}$  in length, made up from the same alloy as the bulb, was provided with a scale and its length measured in a special form of comparator at temperature intervals of  $50^{\circ}$  up to  $1000^{\circ}$ . The expansion was found to be  $10^{\circ}\beta = 8.84 + 0.00131t$ , with an error of about 0.5 per cent. An irregularity was detected both in the expansion and subsequent contraction in the region below  $300^{\circ}$ , which appeared variable with the rate of cooling or heating, and in character resembled the hysteresis which appears in a bar which has been subjected

to stress. If the bar was cooled down very slowly, it returned nearly to its initial length; if cooled rapidly, it required several days to return to its original dimensions. This irregularity makes up most of the 0.5 per cent uncertainty mentioned above.

*Plan.*—Above 1100° considerable uncertainty has existed in the temperatures of various fixed points. The melting point of nickel, considered as 1484°,\* has been frequently employed. The curve of the platinum-rhodium thermoelement, extrapolated beyond the copper-point, has been still more generally used, but like any extrapolation, may lead to quite erroneous results. The only gas thermometer comparison that has been made in this region is that of Holborn and Valentiner,† but by their own estimate the accuracy of the upper portion of their scale is not greater than  $\pm 10^\circ$ . The chief purpose of our work was, therefore, to establish the temperature of several fixed points between 1100° and 1600° and to find what curve is followed by the platinum-rhodium thermoelement in this region, with an accuracy comparable to that obtained in the lower portion.

The plan of the work is simple. It consists, first, in selecting certain fixed thermometric points, usually melting points of metals, and in determining their reproducibility; second, in making a measurement of the true temperature on the nitrogen scale at or close by one of these fixed points; third, in transferring this known temperature by means of a thermoelement over to the fixed point in question. This transference by the thermoelement is necessary because the thermometer bulb cannot be put directly into melting or solidifying substances at high temperatures. The relation of electromotive force to temperature for any particular kind of thermoelement does not enter into the problem when the temperatures measured are close to the fixed points; a linear correction is then abundantly accurate. The interpolation curve, for any element, between the fixed points established by the gas thermometer, is therefore a separate matter.

The questions which remain to be answered are, then: (1) How exact and uniform can the temperature of the gas in the bulb be made (independently of any effort to measure this temperature)? (2) How accurately can its pressure be measured in order to establish that temperature on the nitrogen scale? (3) How accurately can this temperature be transferred from the thermometer and compared with the fixed melting point? (4) How accurately can the fixed points be reproduced for purposes of calibration of secondary measuring devices?

As has been stated, our experience has convinced us that the most of the variations in the gas scale temperatures of the

\* Holborn and Wien, *Wied. Ann.*, xlvii, 107, 1892; and lvi, 360, 1895.

† *Ann. d. Phys.* (4), xxii, 1, 1907.

fixed points commonly in use, as given by various observers, are due, not to differences in the properties of different gases used, nor to differences in pressure, nor to differences between the constant-volume and constant-pressure scales, all of which have been frequently discussed from the theoretical standpoint; but to systematic errors residing in the apparatus and the methods employed. A large portion of the present work has therefore been devoted to finding out experimentally the effect of variations in all those conditions which might affect the results systematically.

## 2. *Apparatus.*

In all essential particulars the gas thermometer apparatus is that developed by Day and Clement and already described by them in detail (*loc. cit.*). It consists of four principal parts: (1) bulb, (2) furnace, (3) furnace jacket, and (4) manometer.

(1) *The Bulb.*—A great deal depends upon the material of which the bulb is made. Primarily and obviously, the bulb must be able to hold the expanding gas without absorbing or losing any portion of it throughout the temperature range of the measurements.

A secondary requirement, the importance of which increases rapidly when high accuracy is sought, is that it shall be possible to use several thermoelements in the furnace with the bulb without their readings being endangered by contamination from the bulb material. As long as this intermediary role of the thermoelement remains a necessary one and alloys of platinum continue to provide the only successful bulb material, the contamination\* of the platinum wire of the element by the alloyed iridium or other platinum metal in the bulb will remain a serious consideration in all temperature measurement above 900°.

Although the platin-iridium bulb served well as a gas container, the contaminating effect of the iridium upon the thermoelements made the life of the latter, for measurements of such extreme accuracy, very short. Accordingly, at the close of the first series of experiments, a change was made from the platin-iridium bulb to one of platin-rhodium (80 parts platinum, 20 parts rhodium) 160<sup>mm</sup> long and 47<sup>mm</sup> in diameter. Inasmuch as one of the wires of the thermoelement itself contains 10 per cent of rhodium to which the platinum wire is always exposed (and which gradually contaminates it, too, although very slowly), it was thought that the substitution of a rhodium alloy in the bulb might serve to retain the necessary qualities of stiffness and regularity of expansion with a minimum of disadvantage in the matter of contamination. These expecta-

\*For a detailed account of the behavior and treatment of contaminated thermoelements, see Walter P. White, *Phys. Rev.*, xxiii, 449, 1906.

tions have been completely realized. Although the rhodium alloy is less rigid at temperatures of  $1000^{\circ}$  and beyond than the iridium alloy, and requires more careful adjustment for equal pressure within and without, no sagging of the bulb walls or deformation from the gas pressure has appeared up to  $1550^{\circ}$ . Meanwhile, the contamination of the thermoelements in the presence of the rhodium alloy is now reduced in magnitude about 80 per cent for a given temperature and time of exposure.

(2) *The Furnace*.—The common practice of recent observers (Callendar, Harker, Holborn and Day, Jacquerod and Perrot, Day and Clement) has been to use a cylindrical bulb in which the length was three or four times the diameter, enclosed in a concentric furnace tube (air bath) heated by the electrical resistance of a coil of wire wound upon or within it. To this bulb the heat is applied radially over its cylindrical surface, but no heat is supplied at the ends. The furnace tube itself and the winding of the coils have been changed at different times and in a variety of ways in order to vary the distribution of the heat supply. The arrangement used in most of our experiments consisted of one main coil of platinum wire  $1.2^{\text{mm}}$  in diameter, wound on the inside of a refractory magnesia tube  $36^{\text{cm}}$  long and  $2^{\text{cm}}$  thick. As has been our habit for some years, the windings near the ends of the coil are somewhat closer together than those at the middle, but this device is not of itself sufficient\* to compensate for differences of temperature along the bulb at all temperatures. In a particular case a favorable arrangement will provide an almost perfect temperature distribution at  $500^{\circ}$ , but will overcompensate the ends at  $1000^{\circ}$  sufficiently to spoil the measurements. The conductivity of the bulb metal is wholly inadequate to help out this overcompensation by conveying surplus heat from the ends to the middle of the bulb. On the other hand, a change in the winding which will correct the overcompensation at  $1000^{\circ}$  provides insufficient compensation at  $500^{\circ}$ . The arrangement which has become usual with us is therefore to wind the coil somewhat more closely at the ends than in the middle, with the idea of providing partial compensation for the inevitable heat losses at the ends of the furnace in this way, and in addition, to insert supplementary coils of smaller wire in the ends of the furnace tube in order to provide a small, independently regulated heat supply which can be superposed upon that of the main coil and give the desired uniformity at any temperature likely to be employed. A furnace tube arranged in this way, except for accidental variations, caused, for example, by the flaking off of the fur-

\* Day and Clement, loc. cit., p. 411.

nace lining, affords uniform temperature distribution over a length of 20<sup>cm</sup> in the center of the tube for a range of temperature from 300° to 1550°, and no one temperature is more difficult to regulate than another. This arrangement contains a limitation, however, of considerably greater magnitude than was at first suspected. The ends of the bulb face the comparatively cold ends of the furnace tube and radiate a sufficient quantity of heat toward these cold ends to reduce the temperature of the end surfaces of the bulb some 6 or 8° below the mean temperature of the cylindrical surface.

In so far as this may appear to be a rather obvious condition to be overlooked, it may be remarked parenthetically that it is a common practice of physicists to assume that the temperature is constant over a radial cross-section near the center of a cylindrical furnace which is reasonably long in comparison with its diameter. With this in mind, the probability is even greater that a metallic conductor only 4<sup>cm</sup> in diameter (the end surface of the bulb) perpendicular to the axis in such a furnace will have a uniform temperature between its center and periphery. The fact is that neither of these assumptions is justified, even in furnaces as long as twenty times the diameter. This was shown in a number of actual measurements made under varied conditions, differences of several tenths of a degree being found as low as 300°, and of several degrees at 1000° and higher.

This situation demonstrates the futility of depending upon metallic conductivity (of platinum) to equalize a steep temperature gradient, and again emphasizes the fact, if further emphasis is necessary, that the air bath, or, more explicitly, the temperature distribution within the heating chamber, is the most uncertain factor remaining in gas thermometry.

On account of difficulties in manipulation and accidental leakage into the thermoelement system, we preferred not to introduce additional heating coils into the furnace tube, and accordingly undertook to stop the loss of heat by inserting thin, platinum-covered diaphragms opposite the ends of the bulb. The situation was still further safeguarded, in exchanging the platin-iridium for the platin-rhodium bulb by adding a reentrant tube at the lower end of the bulb, to enable us to measure the actual temperature prevailing at its center as well as over the surface. In this way, we thought to obtain a more representative integral of the surface temperature and a competent comparison of this integral with the temperature actually prevailing at the center of the bulb.

(3) *The Furnace Jacket.*—The furnace jacket was water-cooled and could be closed air-tight around the furnace and bulb together, so that the pressure could be maintained the same within and without the bulb to avoid deformation.

(4) *The Manometer*.—The bulb communicated, by a capillary tube leading out through the furnace jacket, with the manometer, which consisted of two glass tubes communicating through a steel reservoir. At the top of the shorter arm, where the capillary joined it, was a fixed reference point to which the mercury was brought for each measurement of the pressure. A detailed description of the manometer will be found in the previous paper.\*

### 3. Details, Errors and Corrections.

The gas thermometer for high temperatures has now reached a stage of development where it becomes necessary to examine many small sources of error. These will be discussed in the succeeding paragraphs without attempting to classify separately the variable errors of observation, and the systematic errors which may arise from conditions of the measurements or from constant corrections.

To bring out the plan of investigation of these errors, it will be well to recall the derivation of the gas thermometer formula. The gas scale, as is well known, is defined by the relation

$$\frac{pv}{1 + at} = K \quad (1)$$

in which  $K$  and  $a$  are constants and  $t$  is a function of  $p$  and  $v$ , the pressure and volume of a fixed mass of the gas.  $K$  and  $a$  are determined by two further conventions:

When  $p=p_0$  and  $v=v_0$  (at melting point of ice),  $t=0$  (2)

When  $p=p_{100}$  and  $v=v_{100}$  (at boiling point of water),  $t=100$  (3)

It is then evident that

$$a = \frac{p_{100} \frac{v_{100}}{v_0} - p_0}{100 p_0}$$

which defines  $a$  as the mean pressure coefficient of the gas between  $0^\circ$  and  $100^\circ$  (when  $v_{100}$  and  $v_0$  are nearly equal); and

$$K = p_0 v_0.$$

The temperature,  $t$ , is therefore defined by the formula:

$$t = \frac{p \frac{v}{v_0} - p_0}{a p_0} \quad (4)$$

the scale depending upon the gas chosen, the value of  $p_0$ , and the ratio  $\frac{v}{v_0}$ . In the theoretical constant-volume thermometer,

\* Loc. cit., p. 415, and this article, p. 107.

this ratio  $\frac{v}{v_0}$  is unity, but in the experimental constant-volume thermometer it always varies considerably from 1. We have preferred therefore to treat equation (4) as the fundamental equation, introducing in place of  $\frac{v}{v_0}$ , however, the proper function of the expansion coefficient of the bulb material.

Since apparatus designed for high-temperature work is not suited for the most accurate determination of  $\alpha$ ,  $\alpha$  has been treated in this discussion as a separately determined constant.

In the experimental gas thermometer, there is always a small space in the tube connecting with the manometer which is at various temperatures other than  $t$ . The pressure ( $p'$  or  $p_1$ ) actually measured is not therefore the  $p$  or  $p_0$  of the formula. Imagine that this supplementary space is heated up to the uniform temperature  $t$ , without any change in its volume, and let the resulting corrected pressure be  $p$  (or  $p_0$  as the case may be). Furthermore, let

$V$  = volume of bulb at  $t^\circ$ .

$V_0$  = " " " "  $0^\circ$ .

$v_1$  = " " " " "unheated space" which is at temperatures other than  $t$  (or than  $0^\circ$ ).

$t_1$  = temperature of this space.

$\beta$  = linear expansion coefficient of the bulb material.

Under these conditions, formula (4) becomes :

$$t = \frac{1}{p_0 \alpha} \left[ p \frac{V + v_1}{V_0 + v_1} - p_0 \right]$$

$$= \frac{1}{p_0 \alpha} \left[ p \left( 1 + \frac{3\beta t}{1 + \frac{v_1}{V_0}} \right) - p_0 \right]^* \quad (5)$$

In this formula  $\frac{v_1}{V_0}$  is a very small correction term ; while the important quantities to be measured are  $p_0$ ,  $p$ ,  $\alpha$  and  $\beta$ . The ratio  $\frac{v_1}{V_0}$  becomes of importance, however, in determining the corrected pressure  $p$  from the measured pressure  $p'$ . The derivation of this correction is as follows :

The mass of the gas in the unheated volume under the actual conditions of measurement is proportional to  $\frac{p'v_1}{1 + \alpha t_1}$  ;

$$* \frac{V + v_1}{V_0 + v_1} = \frac{\frac{V}{V_0} + \frac{v_1}{V_0}}{1 + \frac{v_1}{V_0}} = \frac{1 + 3\beta t + \frac{v_1}{V_0}}{1 + \frac{v_1}{V_0}} = 1 + \frac{3\beta t}{1 + \frac{v_1}{V_0}}$$



the mass of the gas within the bulb is proportional to  $\frac{p'V}{1+at}$ .

If we now suppose the unheated space raised to the uniform temperature  $t$  without change of volume, the pressure being thereby raised to  $p$ , the total mass is proportional to  $\frac{p(V+v_1)}{1+at}$ .

Therefore,

$$\frac{p'v_1}{1+at_1} + \frac{p'V}{1+at} = \frac{p(V+v_1)}{1+at}$$

whence

$$p-p' = p' \left( \frac{v_1}{V+v_1} \cdot \frac{at-at_1}{1+at} \right)$$

This correction is easily calculated and tabulated; or, better, the factor in parenthesis (in the second member of the equation) is plotted against temperature. In practice, the volume  $v_1$  is divided into three portions at temperatures  $t_1'$ ,  $t_1''$ , and  $t_1'''$  as explained on p. 109, and the corrections obtained from the curve for each of these portions are simply added together to obtain the total correction  $p-p'$ . With these corrected pressures,  $p_0$  and  $p$ , the temperature  $t$  is calculated by formula (5) on page 101.

The discussion of errors and corrections will now be taken up under the general outline sketched on page 96.

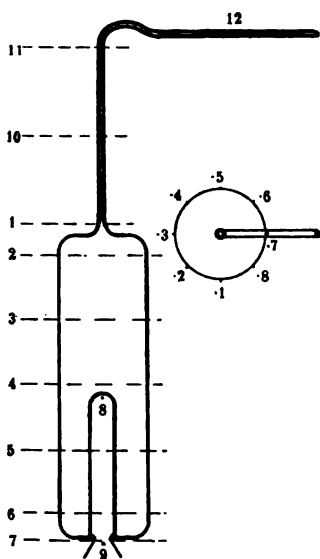
*A. Temperature of the Gas in the Bulb.* (a) *Uniformity.*—Above the temperatures where a liquid or vapor bath can be used to secure uniformity, the differences of temperature between different parts of a furnace has always been a serious limitation to the accuracy of the gas thermometer. This variation, even in a furnace containing well-conducting materials, is much larger than has usually been assumed, and the three equalizing factors of conductivity, radiation, and convection by air-currents, are all credited with much greater influence in bringing about uniformity than they really possess. It sometimes happens that our faith in these factors is inversely proportional to our quantitative information.

To remove this source of uncertainty, Day and Clement introduced two auxiliary heating coils in the furnace, one at each end, and by varying the three independent currents, brought the temperature at the middle and at both ends, on the outside of the bulb, to equality.

In our first measurements with the new bulb, the end elements were placed on the axis of the bulb, in positions 1 and 9 (fig. 1), instead of on the outside surface. It became evident at once that the supporting tube in the bottom of the furnace, used in the work of Day and Clement, had a consid-

erable cooling influence on the central portion of the bottom, an effect which would tend to make their results low. This effect was largely obviated by using, in place of the heavy magnesite tube, a thin Marquardt porcelain tube in the top of which was placed a Marquardt crucible, cut out into a three-pronged support. The bottom of the crucible acted as a screen to prevent radiation from the bottom of the bulb, and the smaller thickness and thermal conductivity of the tube practically prevented the loss of heat from the bottom by conduction. Later, a second diafram was added, about 1<sup>cm</sup> lower down, primarily

FIG. 1.



SECTION.

FIG. 1a.



FIG. 1. Numbers indicate the positions of the thermoelements grouped about the bulb.

FIG. 1a. A photograph of the bulb made after the palladium-point determination showing all the elements and the diaframs in position.

for the purpose of centering the tube and bulb in the furnace, but without noticeable effect on the temperature distribution.

In addition to the three thermoelements mentioned, a fourth was located inside the reentrant, in position 8.\* Several trials under varied conditions confirmed the fact that this element, when the other three were set equal, was 2° to 3° hotter than the one on the outside. A thorough exploration of the dis-

\*See fig. 1, and note, p. 104.

tribution of temperature over the surface of the bulb was therefore undertaken.

Since the number of wires which could be led out through the packed joints was limited, the plan was adopted of using the bulb itself as a differential thermoelement, single platinum wires being tied to the bulb at points whose temperature was to be determined. Each of these wires formed, with the platinum of the standard element tied to the bulb at the middle, a differential element which would read zero if the wires were alike and if no difference of temperature existed between the two points on the bulb.

The relation of the wires was established by sealing each in turn to the platinum of the standard, and measuring their E.M.F. at various temperatures. The readings varied, according to the quality of the wire, from 0 to 40 microvolts. The method of evaluating differences of temperature, when such existed, is discussed on page 118.

The distribution of temperature lengthwise of the bulb was first investigated, and auxiliary wires were placed at the levels 1 (base of stem), 2 (top shoulder), 6 (bottom shoulder), 7 (bottom, outside of funnel), in addition to thermoelements at 4 (middle outside), 8 (inside reentrant), and 9 (bottom, just inside of funnel).\*

With this system of thermoelements, it was found that at 1082°, when 9 was brought to equality with 4 and 1, the bottom of the bulb was superheated 6 to 8° at position 6, and about 4° at 7, due entirely to the fact that the thermoelement at 9, not being in contact with the bulb, lost sufficient heat by conduction and radiation downward to keep its temperature below that of the metal surrounding it. The element at 8, on the other hand, received heat by conduction up the reentrant tube and by radiation from below, which made it read higher than the element at the same level outside. The element at position 9 was therefore discarded and each setting of temperature made with reference only to the elements which were attached directly to the bulb.

The temperature between the middle and the top shoulder was also examined in several experiments. The temperature at this position was found to be within 0.5° of the other two, with a tendency to be lower than these.

Further experiments showed that in addition to the possibility of vertical variation of temperature, there was a varia-

\* The system of numbering the positions of elements on the bulb is shown in fig. 1. The figure before the decimal point indicates the horizontal level, the figure after the decimal indicates the orientation around the bulb. For instance, an element in position 3.5 would be about half way between the top and middle and on the side of the bulb away from the front of the apparatus.

tion around the circumference of the bulb. This amounted in the worst case (at  $1450^{\circ}$ ) to a variation of  $1.3^{\circ}$  from the mean, four elements being used around the circumference to make the test. This variation seemed to be due either to unequal conductivity of the furnace material at different points or to the falling off of small portions of the furnace lining, leaving exposed places on the wire. Variations of this character are probably an unavoidable result of using a furnace where the heat supply is so near to the point where it

FIG. 2.

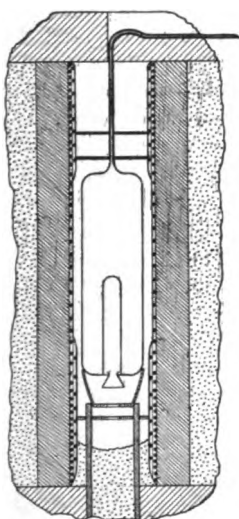


FIG. 3.

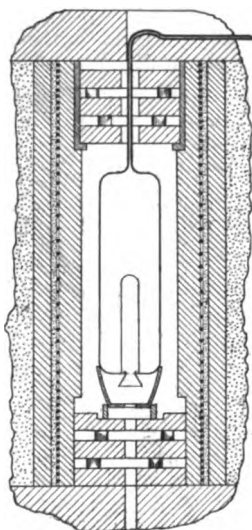


FIG. 2. Section of furnace and bulb showing the arrangement of coils and diaframs about the bulb which gave the most uniform temperature distribution in the measurement of both high and low temperatures. The supplementary end coils were independently heated and regulated.

FIG. 3. A special arrangement of the heating coil and diaframs designed to give a very uniform temperature distribution about the bulb. The coil was heavily ballasted inward with a good heat conductor and outward with a poor conductor. The heating coil was also divided into three sections which could be independently regulated. This furnace was used at the copper point only.

is measured, as is the case with the furnace which is wound on the inside. This form of winding is necessary, however, in order to reach the highest temperatures, so that absolute uniformity of temperature around the bulb had to be sacrificed to increased range of the instrument.

After this variation was discovered, measurements were always made with four elements at equal distances around the

circumference of the bulb and the mean of their readings was taken.

In order to be perfectly certain that no systematic error was being introduced by using this one form of furnace (fig. 2.) throughout, it was replaced temporarily by a furnace of platinum wire wound on the *outside* of a similar tube. In this way a heavy mass of good heat-conducting material was introduced between the source of heat and the bulb, with the expectation that a more uniform temperature might thereby be obtained in the inside space. The two types of furnace are shown in figs. 2 and 3.

A measurement at the copper point with the outside-wound furnace gave as the melting point of copper  $1082.6^{\circ}$ , which differs only  $0.4^{\circ}$  from  $1082.2^{\circ}$ , the mean of the results obtained at the same pressure with the other furnace, and is identical with the final mean of all the results, thus proving that no systematic error was to be feared from the inside-wound type of furnace. The horizontal uniformity obtained in the outside-wound furnace was better than that in the inside-wound, but the furnace was more difficult to regulate and to hold at a given temperature.

(b) *Constancy of Conditions*.—Several causes interfered with the establishment of a constant temperature for observation. The three heating currents required constant observation and readjustment with the gradual extension of the heated zone toward the outside of the furnace. This comes to equilibrium for a particular temperature after about half an hour, after which the bulb was held steady 15–30 minutes longer before readings of the pressure were taken. The temperature thus established could be relied upon to remain constant to within 1 to 3 microvolts ( $0.1^{\circ}$  to  $0.3^{\circ}$ ) during the course of the pressure measurements.

Above  $1100^{\circ}$  a noticeable leakage of current from the heating coil into the bulb and thermoelements frequently appeared. This may have been due in part to conductivity across the narrow air space between bulb and coil, but was probably chiefly due to accidental contact between the protecting tube of one of the thermoelements and the furnace wall. To obviate any uncertainty from this cause, it was found necessary to use alternating current for all temperatures above  $1100^{\circ}$ . This was less easy to regulate than the direct current from storage batteries, but by careful regulation of the voltage of the motor generator supplying the alternating current, equally satisfactory results were obtained.

The constancy and exactness of the temperature at  $0^{\circ}$  were beyond question. On several occasions pressure measurements at  $0^{\circ}$  were made at intervals of one-half to one hour and no

measurable difference found. Similarly, repacking the bulb in a fresh supply of ice gave exactly the same value.

*B. Definition of Temperature by Measurements of Pressure.*—The procedure in measuring the pressure,  $p'$ , was as follows: First the three mercury thermometers on the manometer were read to determine the temperature of the mercury column and scale; then three to four settings of the barometer were made, alternating with measurements of the manometer. The mercury thermometers were read again at the close. During this interval the other observer made as many readings as possible of all the thermoelements.

Before the manometer was connected to the bulb, the point on the scale corresponding to the reference point of the manometer\* was determined once for all before the manometer was connected to the bulb, by connecting the two arms and raising the mercury to the point, as in a regular pressure measurement. Subsequent manometer readings were subtracted from this fixed level, and the resulting difference corrected for the temperature and calibration corrections of the scale and then reduced to  $0^\circ$ . The barometer reading was similarly corrected. The algebraic sum of the two gave the pressure  $p'$ , in terms of a centimeter of mercury at  $0^\circ$  and at the latitude and elevation of the laboratory. Since the absolute value of the pressure does not enter into the gas thermometer formula, corrections for altitude and latitude are superfluous.

*Errors and Corrections in  $p'$ .*—The level of the fixed reference point of the manometer varies with the temperature of the room because of the difference in expansion of the brass scale on the one hand and of the glass tube of the manometer which carries the fixed point on the other. This correction can be calculated from the expansion coefficients of the materials and amounts to  $0.04^{\text{mm}}$  per  $5^\circ$ . Its direction and amount were checked experimentally by determining the fixed point at two temperatures differing by about  $10^\circ$ , the room being open on a cold day for the one case, and then closed and heated for the other. The difference found was  $0.09^{\text{mm}}$ , and that calculated  $0.08^{\text{mm}}$ .

The lengths of the divisions of the brass scale were corrected for change of temperature by a formula determined for this scale at the Normal-Aichungs-Kommission, the absolute length of the scale having been determined at  $16^\circ$ . In addition, calibration corrections, determined for each millimeter of the scale, were applied. The total scale correction was always less than  $0.15^{\text{mm}}$ , hence the temperature measurement by the adjacent mercury thermometers was abundantly accurate for this purpose.

\* p. 100.

The length of the mercury column was reduced to  $0^\circ$  by the expansion coefficient given in the Landolt-Börnstein-Meyerhoffer Tabellen. This correction varied from 0 to about  $3.00^{\text{mm}}$ . As the mercury thermometers were calibrated and read to  $0.1^\circ$ , the uncertainty in this correction due to uncertainty in the room temperature may amount to  $0.05^{\text{mm}}$ . For the calibration the mercury thermometers were compared with a Richter standard thermometer calibrated at the Reichsanstalt.

The barometer reading was corrected to  $0^\circ$  by the Landolt-Börnstein-Meyerhoffer table for barometer with brass scale. Two Fuess barometers were used. Both had been tested by the Bureau of Standards; one had an absolute correction of  $0.06^{\text{mm}}$ , the other was exact. This was checked by direct comparison of the two. The variable error in the barometer is probably about the same as in the manometer reading ( $0.05^{\text{mm}}$ ). On a very windy day or during the approach of a storm, the barometer was too unsteady to permit satisfactory measurements to be made.

A further small correction to the barometer was necessary to allow for the weight of the air column between the cup of the barometer and the top of the mercury in the open manometer column. This correction was appreciable, amounting to  $0.16^{\text{mm}}$  in the extreme case.

To give some idea of the effect of these small corrections upon the final temperature measurement, it may be added that  $1.00^{\text{mm}}$  corresponds approximately to  $1^\circ$ .

To determine the corrected pressure,  $p$ , from the measured pressure,  $p'$  (see page 101), the volume of the unheated space,  $v_1$ , connecting the bulb with the manometer, must be known.\*

TABLE I. — *Unheated Space.*

Space	Volume, c.c.		Uncertainty		Max. effect at Cu. pt. of errors
	Before Apr. '09	After Apr. '09	of vol.	of temp.	
Pt-Rh capillary, bulb to top furnace ( $v_1'$ )	0.055	0.055	0.002	$100^\circ$	$0.04^\circ$
Pt-Rh capillary, top to out- side furnace ( $v_1''$ )	0.086	0.086	0.003	$50^\circ$	$0.20^\circ$
Pt-Rh capillary to gold capillary	0.102	0.054	0.015	$0.5^\circ$	$0.20^\circ$
Gold capillary	0.094	0.066			
Pt capillary and Ni valve	0.025	0.025			
Space above meniscus	0.023	0.023			
Total	0.385	0.309			$0.45^\circ$

\* See discussion of this correction, Day and Clement, loc. cit., p. 410.

This was calculated from the dimensions of the capillary. The figures are given in Table I. This volume was reduced in April, 1909, by bringing the manometer closer to the furnace, since the water jacket of the furnace cut off the heat so completely that there was no risk in bringing the manometer as close as possible ( $35^{\text{cm}}$ ). The volume  $v_1$  was thereby reduced from  $0.39^{\text{cc}}$  to  $0.31^{\text{cc}}$ , and the ratio  $\frac{v_1}{V}$  from  $0.00187$  to  $0.00150$ .

The volume,  $V$ , which enters into the correction term (see page 102) was determined by weighing the bulb empty, and filled with distilled water at a known temperature. A very accurate determination of this volume was not necessary, the important requirement being that the volume should not change during a run. A check on change of volume was obtained in the measurement of the value of  $p_0$ . The volume of the bulb at  $0^{\circ}$ , up to the base of the capillary stem, was found to be :

On 13 June, 1908 (new) . . . . .	$205.74^{\text{cc}}$
On 18 " " (after $1450^{\circ}$ ) . . . . .	$205.75^{\text{cc}}$
On 20 Apr., 1909 . . . . .	$205.82^{\text{cc}}$

The volume of the unheated space,  $v_1$ , was arbitrarily divided into three portions for the convenient determination of its average temperature,  $t_1$ . The first portion,  $v_1'$ , extended from the base of the stem to the top of the upper brick of the furnace (see fig. 2); the second portion,  $v_1''$ , included the capillary stem as far as the outside of the furnace; the third portion,  $v_1'''$ , extended to the surface of the mercury in the manometer and included all of that portion of the unheated space which remained at room temperature.

The temperatures of the portions  $v_1'$  and  $v_1''$  were determined by placing a thermoelement at different points along the stem during several of the runs. As this temperature does not need to be known accurately, a few measurements gave a sufficient indication of the distribution of temperature in the portion of the "unheated space" within the furnace.

A liberal estimate of the degree of uncertainty in the values of  $v_1$  and  $t_1$  has been made and is included in Table I, together with the effect which such errors would have on the calculated temperature,  $t$ , at the copper point.

*Errors and Corrections in  $p_0$ .*—The same instrumental corrections apply to  $p_0'$  as to  $p'$ , but their proportional magnitude is, of course, larger. The values of the uncertainty in  $t$  due to these small errors will be found in Table IV.

Changes in the value of  $p_0$  (the ice point) after heating to high temperatures have always been disturbing factors in gas thermometer measurements and have introduced uncertainties of a very intangible kind. This was especially true of the



porcelain bulbs formerly used, where both changes of volume and emission or absorption of gases by the walls occurred. The restoration of the platinum metals to favor as materials for the gas thermometer bulb has practically eliminated this uncertainty. During the present work small changes in the value of  $p_0$  have frequently occurred after heating to a high temperature, which seem not to be due to any change in volume, for the determinations of the volume,  $V_0$ , given above (p. 109), show a total change after a year's work corresponding to less than  $0.1^{\text{mm}}$  in  $p_0$ . In the early part of the work, the passage through the bulb wall of hydrogen or some other gas produced by the reducing action of wood fiber in an asbestos board insulator within the furnace, was suspected as being the cause of irregularity, particularly in view of the fact that Holborn and Valentiner had difficulties from this cause. Further, it was several times observed that heating the furnace and bulb to a higher temperature than they had reached before, caused a slight increase in the value of  $p_0$ ,—whether due to some gas passing in from the outside, or coming out of the wall of the bulb, is not known. Air dried over calcium chloride was used outside of the bulb in the furnace enclosure throughout the work, and no indication was ever obtained of the passage of either oxygen or nitrogen through the wall of the bulb, since measurements at a given temperature (after the first heating to that temperature) gave the same value of  $p_0$  within the error of measurement.

On one occasion an almost inappreciable leak in the manometer connection caused some uncertainty. All measurements affected by this error, when it was discovered, were rejected.

$\alpha$ .—Since the gas thermometer apparatus as arranged for high temperature measurements is not suited to a determination of the value of  $\alpha$  (the pressure coefficient of the gas from 0 to  $100^\circ$ ) with an accuracy comparable to that attained by Chappuis,\* the value of  $\alpha$  was treated as a constant. The figures used were:

$$\text{For } p_0 = 345 - 347^{\text{mm}}, \alpha = 3665.8 \times 10^{-6}$$

$$\text{For } p_0 = 217 - 221^{\text{mm}}, \alpha = 3664.0 \times 10^{-6}$$

A number of independent determinations of  $\alpha$  for different pressures were made by Day and Clement† with the platinum bulb, but they show no appreciable difference from those by Chappuis within the experimental error of the apparatus. The probable error in Chappuis' results is not great enough to affect the high temperature values.

\* Trav. Mem. Bur. Int., vi and xii, 1888 and 1902.

† Day and Clement, loc. cit., p. 442.

Pure nitrogen was used throughout as the thermometric gas.\* The storage tank was refilled several times so that not all the gas was from the same original supply; the filling of the bulb was also changed several times. The bulb was first completely evacuated and heated to a high temperature, after which the connections and bulb were rinsed out several times with the purified gas before the final filling.

*Expansion Coefficient of the Bulb.* ( $\beta$ ).—The substitution of a new alloy in place of the platin-iridium made necessary a new determination of the expansion coefficient of the bulb material. The method of its determination and the comparator used for the purpose were fully described in the earlier article† and do not require to be repeated here.

Three additional precautions were taken in carrying out the measurements: The bar was increased in length to 0.5 meter, and in diameter to 6<sup>mm</sup>, in order to increase the sensitiveness of the determination and the uniformity of temperature along the bar respectively. In this case the bar was also made at the same time and from the same alloy as the bulb itself, and was therefore identical with it in composition.‡

In ruling the bar, the lines were spaced 0.2<sup>mm</sup> apart instead of 0.5<sup>mm</sup>, as in the previous investigation. This enabled a greater number of observations to be made within a narrow region than heretofore, and has thus made it possible for us to avoid the error from parallax described in the previous paper.§

The third precaution involved a slight change in the comparator itself, and was made at the suggestion of Chappuis. Our custom had been to verify the distance between the fixed hairs of the microscopes before and after each heating by measuring this distance in terms of a standard brass bar calibrated at the Bureau of Standards. The brass bar was then replaced by the platin-iridium bar before the heating began, and the length of the latter was measured in terms of the initial distance between the fixed hairs, at intervals of 50° or

\* It was prepared by dropping a solution of 200 grams of sodium nitrite dissolved in 250 grams of water, into a warm solution containing 350 grams of ammonium sulphate and 200 of potassium chromate in 600 of water. It was passed through a mixture of potassium bichromate and sulphuric acid and stored over water. For use in the gas thermometer it was purified by passing through calcium chloride, hot copper gauze, potassium bichromate in sulphuric acid, 2 bottles potassium pyrogallate solution, sulphuric acid, calcium chloride and phosphorous pentoxide.

† Day and Clement, loc. cit., p. 425.

‡ The new bulb, as well as the bar, were made with the utmost care by Dr. Heraeus, of Hanau, Germany, for this investigation. We have had repeated occasion in the past to make public expression of our indebtedness to Dr. Heraeus for his interest and assistance in this work, and it is a pleasure to repeat this acknowledgment here.

§ Day and Clement, loc. cit., p. 435.

100° up to 1000°. This mode of procedure involved the assumption that the agreement of the measurements made before and after heating afforded adequate proof that no change had taken place *during* heating. The justification for this assumption lay in the fact that, (1) the furnace was completely water-jacketed to prevent any heat reaching the microscopes from the furnace; (2) suitable insulating material introduced between the observer and the microscopes cut off any disturbing influence from the near approach of the observer's body; (3) the microscopes themselves, and the carriages upon which they were mounted, were connected by carefully selected invar bars

FIG. 4.

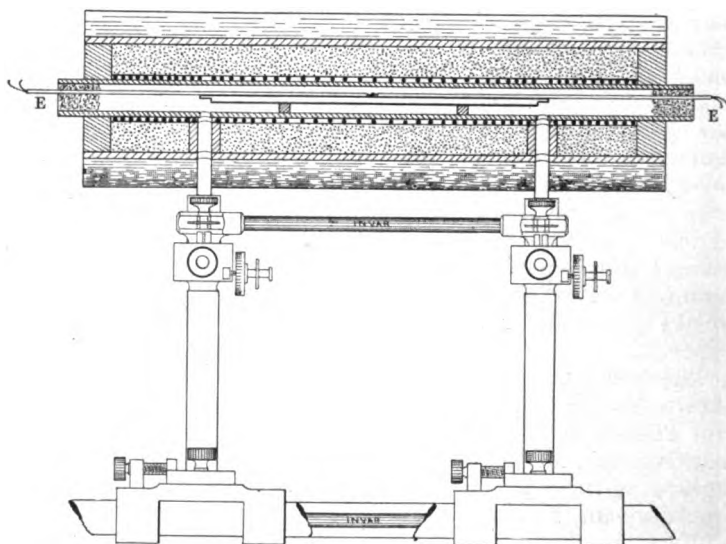


FIG. 4. Section through furnace showing bar, thermoelements (E, E) and microscopes in position. A section through the arrow is shown in fig. 5.

of negligible expansion coefficient, and, finally, (4) the faithful agreement of all the measurements before and after the many heatings left no reason for suspecting a variation.

Notwithstanding these conditions, it appeared to Chappuis that some positive proof should be offered that the distance between the cross-hairs remained unchanged while the heating was going on, inasmuch as all the measurements were made in terms of this distance. Accordingly, at his suggestion, it was arranged to retain a standard unheated bar in the field of the microscopes throughout the readings, so that the distance between the cross-hairs would be subject to check at any time

during the observations. The arrangement made for the purpose is very simple and effective, as can be seen from the neighboring diagrams (figs. 4 and 5). The last two series of measurements were made with this appliance, and the fixed distance was found to remain constant throughout the series to within  $0.003\text{mm}$ , although on first setting up the apparatus a gradual adjustment of strain, amounting to  $0.012\text{mm}$ , took place during the first two days.

The determination of  $\beta$  is subject to two errors; the first is uncertainty of temperature, the second occurs in the measure-

FIG. 5.

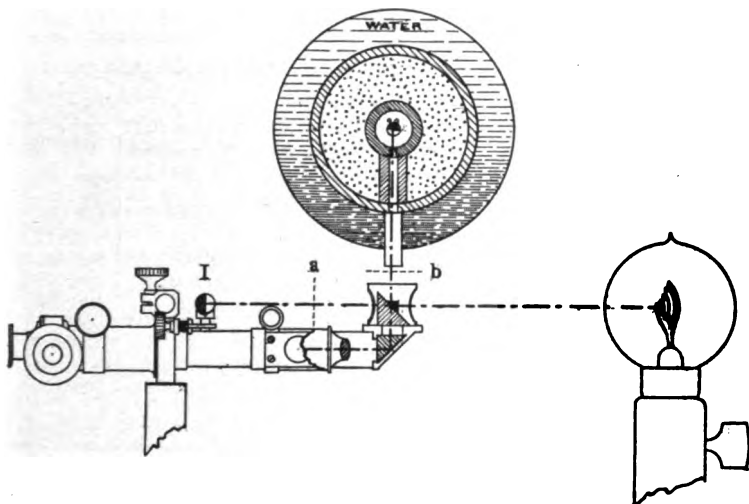


FIG. 5. A section through the furnace at one of the openings, showing the method of illumination of the heated bar and the standard cold bar (I) together with an arrangement for checking the distance apart of the cross hairs at each temperature. With a screen inserted at *a* only the hot bar is visible; with the screen at *b* only the cold bar.

ment of the change in length. It was impossible to wind the furnace ( $70\text{cm}$  long and  $2\text{cm}$  inside diameter, with two side openings) so as to give a perfectly uniform temperature along the bar; but as the furnace winding and consequent distribution of temperature were varied considerably for each run, the uncertainty from this cause was eliminated in the average of all the observations. The error in the temperature measurement itself was probably not over  $2^\circ$ , which would give an error of less than  $0.2$  per cent at the highest temperature. Two thermoelements with a common junction were used, one entering from each end of the furnace. This not only gave a second temperature reading in confirmation of the first, but

a positive check upon the appearance of contamination in the thermoelements.\*

With a half meter bar and a temperature interval extending from zero to  $1400^{\circ}$ , the total expansion amounts to about  $7.8^{\text{mm}}$ . The micrometers reading the expansion were read with an accuracy of  $0.002^{\text{mm}}$ .

There was some indication of a very small hysteresis in the expansion and contraction. Although the amount was not much greater than the experimental error, the measurements indicate that the bar was slightly shorter after heating than before, and that it gradually regained its original length.

The measurements at room temperature are given in Table II. The five measurements in this table which were made

TABLE II.—*Length of Platinum-Rhodium Bar.*

Date	Max. preceding temperature	Length at $0^{\circ}$	Date	Max. preceding temperature.	Length at $0^{\circ}$
1 July 1908	(New)	500.068	26 Sept. 1908	$1150^{\circ}$	500.094
6 " "	$900^{\circ}$	500.110*	1 Oct. "	$25^{\circ}$	500.119
9 " "	$28^{\circ}$	500.105	6 " "	$1300^{\circ}$	500.084†
13 " "	$900^{\circ}$	500.098*	27 " "	$900^{\circ}$	500.108*
17 Sept. "	$900^{\circ}$	500.108*	30 " "	$1400^{\circ}$	500.096
19 " "	$1200^{\circ}$	500.090	6 " 1909	$28^{\circ}$	500.108
20 " "	$28^{\circ}$	500.105	12 " "	$22^{\circ}$	500.108*
22 " "	$1200^{\circ}$	500.087	13 " "	$1000^{\circ}$	500.109
24 " "	$24^{\circ}$	500.096	15 " "	$1400^{\circ}$	500.074†

\* After interval of 4–7 days.

† Bent, after heating beyond last temperature at which measurements were made.

within a few hours after the bar had cooled from a high temperature, excluding the two where the bar was bent, average 500.095; while the ten measurements (excluding the first) which were made two days or more after heating, average 500.106. The difference is only 0.002 per cent of the total length, or 0.12 per cent of the total expansion to  $1500^{\circ}$ , or about 0.7 per cent of the expansion to  $300^{\circ}$ . This effect is, therefore, probably responsible for the observed irregularities between  $0^{\circ}$  and  $300^{\circ}$ , at which temperature most of the measurements were begun.†

*C. Transference of Temperature by the Thermoelement.—*

The electromotive forces of the elements attached to the bulb were measured by a Wolff potentiometer. The standard of

\* Day and Clement, loc. cit., p. 419.

† Kammerlingh-Onnes (Konink. Ak. Wet. Amsterdam, Proc., **x**, 342, 1907) has found the same effect after cooling platinum to very low temperatures.

electromotive force used was the true volt, in terms of which the E.M.F. of the Clark cell is 1.4328 at 15°, and of the saturated cadmium cell used, 1.01918 volts at 25°.

Several small corrections are necessary in order to obtain the true E.M.F. of the thermoelement. The calibration corrections of the potentiometer (Reichsanstalt calibration) were all negligible except that for the fixed resistance to which the standard cell was attached. This correction amounted to 1.3 microvolts in 10,000. The correction for the change of resistance with temperature of the potentiometer was also negligible. The E.M.F. of the standard cell varies with the temperature; hence the temperature of the cell was read at each measurement and a small correction applied. The readings were correct at 21.5°. For a variation of 5° from this temperature the correction was 2.2 microvolts in 10,000 microvolts. The resistance of the contacts of the potentiometer, and the small E.M.F.'s existing at contact points in the circuit of the thermoelement, introduced another small error which was determined by placing the thermoelement in ice and reading the E.M.F. This correction varied for the different elements from -1 to +4 microvolts.

As a check upon the absolute value, a Weston standard cadmium cell (calibration by the Bureau of Standards) whose E.M.F. was read directly on the potentiometer, was compared with the saturated cell each day. The agreement of the corrected values was usually within 0.5 microvolt. As in the case of the pressure measurement, the absolute value of the E.M.F. is not of importance, since it is used only for transference from the fixed points to the gas thermometer; the above corrections were applied, however, to reduce the readings to a common standard.

The effect of contamination of the thermoelement wires in furnace readings was much greater than the above mentioned errors.\* Up to 1100° the contamination was not serious, but above that temperature the wires take up iridium together with some rhodium. It was hoped that the replacement of iridium in the bulb by rhodium, which is very much less volatile, would do away with this error, but there appeared still to be a very small percentage of iridium in the furnace wire, enough to affect the thermoelement wires appreciably, even though this furnace wire had been especially purified for this purpose.

Although the task became much longer and more laborious, it was thought wise to make an effort to avoid the error from contamination, even of this diminished magnitude, rather than to attempt to compromise with it by any scheme of approxi-

\* For a more thorough discussion of this effect, see Day and Clement, *loc. cit.*, p. 419; and W. F. White, *Phys. Rev.*, xxiii, 449, 1906.

mate evaluation. Accordingly, after every exposure of sufficient length to endanger the thermoelectric readings, all the thermoelements were removed from the furnace and their wires tested for homogeneity. Where contamination was found, the contaminated portion of the wire was at once cut off. This is the only absolutely safe method of avoiding errors from this cause, for it amounts to the use of new thermoelements exclusively in all the determinations of temperature distribution within the furnace as well as for establishing the absolute temperature of the metal melting points.

A very simple method of testing the wires for contamination has been developed which consists in connecting the junction end of the wire to be tested, together with an uncontaminated wire, to the potentiometer and moving the free end of the standard wire along the wire to be tested, while heating the contact point of the two with a blast lamp.\* The variation of the E.M.F. produced at this junction indicates the degree of contamination of the wire; in the uncontaminated portion this E.M.F. is small and constant within 3 mv. The temperature obtained by the blast lamp flame is sufficiently constant for the purpose and lies between  $1460^{\circ}$  and  $1500^{\circ}$ .

The wires could be relied upon to give a constant E.M.F. within 2 mv. at  $1000^{\circ}$  over a length of at least  $50\text{cm}$ , so that redeterminations of the fixed points were not necessary after cutting off each small portion of contaminated wire. Each test for contamination was continued over the  $50\text{cm}$  of wire adjacent to the hot junction and so served as a test for the homogeneity of the new wire which replaced the portion cut off. In two cases a sudden change of E.M.F. along the unused wire amounting to about 10 mv. showed the probable presence of a junction point in the original sample from which the wire was drawn. Such a junction point was of course not introduced into the heated portion of the furnace.

In this connection, it should be pointed out that the relative weight to be given to the element inside the bulb, as compared with the outside elements, is greater at temperatures above  $1100^{\circ}$  than at temperatures below, for two reasons: (1) The temperature at the middle of the bulb is not so much influenced above  $1100^{\circ}$  by the temperature of the lower part of the furnace, as it is below  $1100^{\circ}$ ; (2) the outside elements are much more subject to contamination than the inside element by reason of the protection afforded by the intervening bulb walls against contaminating material from the heating coils. This is well shown by the data in Table VIII on the melting points of diopside, nickel and cobalt. In the first measurements of these temperatures, the elements were left on the bulb through

\* W. P. White, loc. cit.

several runs, in consequence of which the temperatures derived by the outside elements steadily increase through the series (i. e., the readings of the outside elements on the bulb steadily decreased), whereas the temperatures derived from the inside element are fairly constant. Its contamination was found to be less in amount and distributed over a region of more constant temperature.

For insulating the thermoelement wires from the bulb and furnace, capillary tubes, both of Marquardt porcelain and of silica glass, were employed. The Marquardt tubes are open to the objection that they are very porous and offer little protection against contamination. The silica glass capillaries protected the wires very much better, but at 1100° and above they devitrified rapidly and at the end of a measurement at 1400° or over fell from the wires in small fragments, so that the wires had to be taken off and reinsulated after a single run.

For the convenience of others who may confront similar problems, it may be added that such extreme precautions as cutting off the elements at the first sign of contamination are excessive for most purposes. The region of highest temperature, and therefore of most rapid contamination in a good furnace, is also a region of constant temperature. Contamination would therefore produce little effect upon the reading of the thermoelement until it had crept out into the colder parts of the furnace, which it will do slowly during long exposures. The distribution of the contamination in an aggravated case is shown in the accompanying table, which is arranged in such a way that not only the magnitude of the contamination but also its distribution with respect to the bulb is roughly shown. The electromotive forces are determined, as has been explained, by bringing successive points of the contaminated

		Before Heating. Microvolts	After Heating. Microvolts
	40 <sup>cm</sup>	—4	—4
Outside of furnace	35	—6	—8
	30	—8	—7
	25	—9	—6
	20	—6	—10
Bend of stem	15	—5	—3
	12	—5	+2
	10	—5	+9
	8	—5	+83
Shoulder of bulb	6	—5	+83
	4	—6	+41
	2	—6	+55
Middle of bulb	0	—8	----



wire into contact with an uncontaminated one in a blast flame (temperature, 1460–1500°), the cold junction being maintained constant at 0°. The absolute magnitude of the numbers in the column “before heating” represents the electromotive force between two uncontaminated platinum wires of (nominally) equal purity. Its constant value is a measure of the homogeneity of the new wire. Its departure from this constant value “after heating” is a measure of the contamination it has received. Slight irregularities are the result of variations in the blast flame temperature. Such observations merely serve to furnish information about the distribution and approximate amount of contamination received by the element, but do not of themselves provide the data to correct its reading in a particular furnace.

*Integration of Temperatures over the Bulb.*—By the method which has been already described (p. 104) the differences of temperature between the ends of the bulb and the middle were determined differentially by means of platinum wires attached to the bulb itself. Temperatures about the circumference were measured by separate thermoelements, as it was not practicable to measure these differences differentially because of the necessity of passing a platinum binding wire around the bulb to hold the four elements in position. A check on the accuracy of this differential method was obtained by using in one case a thermoelement at the top shoulder of the bulb and thus measuring the temperature at this point both directly and differentially by means of the platinum wire of this element. The two temperatures agreed within 0.8° when the deviation from the middle was 6°; when the temperatures at the middle and top were nearly equal, the two methods agreed to 0.1°.

Table III contains values of  $\frac{\Delta E}{\Delta t}$ , the rate of change of E.M.F. with temperature at various temperatures from 400° to 1500°, both for the 10 per cent rhodium alloy and for the 20 per cent

TABLE III.—Values of  $\frac{\Delta E}{\Delta t}$  for the alloys 90 Pt. 10 Rh. and 80 Pt. 20 Rh.

Temp.	90 Pt. 10 Rh.	80 Pt. 20 Rh.
400°	9.4	11.5
600°	10.1	12.8
800°	10.8	14.2
1000°	11.4	15.6
1200°	11.8	16.9
1400°	12.2	17.5
1500°	12.4	17.8

alloy of which the bulb was made. The data for the 20 per cent alloy (which need be only approximate) were obtained by two methods: (1) An element was made up by combining a platinum wire with the 20 per cent rhodium bar used for the expansion coefficient determination, and its readings compared directly with those of a 10 per cent rhodium element in the melting point furnace. (2) A platinum wire was connected from the stem of the gas thermometer bulb outside of the gas thermometer furnace to the ice box, and the E.M.F. determined against the standard platinum wire attached to the middle of the bulb. In both cases, the E.M.F. of the junction of platinum with the rhodium alloy at room temperature was applied as a correction.

In order to obtain the true E.M.F. corresponding to the temperature as measured by the pressure of the gas in the bulb, it is necessary to integrate the various readings over the surface of the bulb. The following arbitrary weights were given to the different positions of elements on the surface:

Top axis	(position 1)	5
Top shoulder	( " 2)	20
Middle	( " 4)	55
Bottom shoulder	( " 6)	15
Bottom axis	( " 7)	5

The elements on the axis at both top and bottom, although sometimes deviating rather widely from the others, have comparatively small weight, as they affect only a small portion of the total volume. The element at the lower shoulder of the bulb is given less weight than that at the top because of the smaller volume of the lower half, due to the presence of the reëntrant tube.

It was easy to show experimentally that it matters very little what these relative weights assigned to the different readings may be, since the total correction was usually small. In a number of cases, two different settings of the temperature distribution were made at each temperature, one in which the elements at the top and bottom shoulders of the bulb were made equal to the middle, and one in which the elements at top and bottom on the axis of the cylinder were made equal to the middle. The pressures corresponding to these two settings, reduced to the same reading of the standard element, are shown for several typical cases in the table below.

Date	Temp.	Pressure when 1, 4, and 7 were equal	Pressure when 2, 4, and 6 were equal
22 Jan. 1909	1082°	1038.82 <sup>mm</sup>	1038.64 <sup>mm</sup>
2 July 1909	1395°	1285.43	1285.17
17 Sept. 1909	1489°	1331.40	1330.63

It is evident that even without any correction for the different distribution in the two cases, the readings agreed within  $0.2\text{--}0.8^{\text{mm}}$ , or about  $0.2\text{--}0.9^{\circ}$ , so that the variation between any two arbitrary sets of weights which might be given to the different readings must lie well within this limit.

*The Transfer to the Fixed Points.*—After the thermoelements are removed from the bulb, their E.M.F. at the fixed points must be determined by immersing them in melting or freezing metals or salts. The instrumental corrections to the readings so obtained were the same as in the case of the gas thermometer readings. The error due to contamination was also present above  $1100^{\circ}$ , just as in the gas thermometer furnace, and was a very disturbing factor in determining the melting points of nickel, cobalt and palladium. Its source, however, was not usually iridium vapor from the furnace or rhodium from the wire of the element, but was either vapor of the melting metal itself, or (when a hydrogen atmosphere was used) the products of reduction of silica. In the presence of hydrogen, silica rapidly deteriorates platinum wire by reduction and alloying, as has been shown in this laboratory by Shepherd,\* and elsewhere by several observers. The contamination can be partly prevented by the use of a glazed porcelain tube surrounding the thermoelement, instead of an unglazed magnesia tube; but an additional uncertainty is thereby introduced through the contamination of the melting metal by the melted glaze on the porcelain. For this reason nickel and cobalt did not prove to be as satisfactory fixed points as had been hoped, since it was necessary to melt them in an atmosphere of hydrogen. Palladium, however, can be melted in the open air and serious contamination by silicon thus be avoided, although the palladium itself gradually contaminates the wire.

Above  $1100^{\circ}$  it is better to make direct comparisons of all the elements with one or two whose fixed points have been determined, rather than to contaminate them all by a direct determination. For making these comparisons, the plan first used was to bring a crucible of molten silver to a constant temperature and insert the elements (protected by a glazed Marquardt porcelain tube) successively into the silver bath. There is an uncertainty, however, in these measurements of 2 to 3 mv., caused by small differences of temperature within the tube and to the slight cooling produced by introducing cold wires into the furnace. A better method is to join together the two platinum wires and the two alloy wires of the elements to be compared, and determine the small E.M.F.'s of each pair at several temperatures, from which the difference between the

\* This Journal (4), xxviii, 300, 1909.

elements at those temperatures can be obtained by algebraic addition. This method offers a great advantage in that the temperature need be only approximately constant and approximately known, since the differences in most cases amount to only a few microvolts. By this method the comparison can be very quickly made at  $1500^{\circ}$  in the blast-lamp flame, which, with a little care, can be made to give a temperature constant to  $20^{\circ}$ .

*D. Fixed Points.*—Considerable attention was given in the previous paper to the standard melting points which serve to establish the gas thermometer scale for general use. In particular, a study was made of the purity of the zinc, silver, gold, and copper used, and of the magnitude of the errors likely to arise with the ordinary metals obtainable in the market.\* During the present work, attention has been more particularly directed to the technic of melting point determination itself.†

All the metal melting points here described, except that of palladium, were made in an upright cylindrical furnace through which passed a glazed porcelain tube which could be tightly closed above and below and therefore permitted the atmosphere about the melting metal to be perfectly controlled. An effort was first made to accomplish this by placing the entire furnace inside a gas-tight bomb in which the atmosphere could be similarly varied, but the persistent retention of gases by the various clay insulating materials used about the furnace made this method slow, cumbersome, and very uncertain in its results. The only success which these bomb furnaces attained was to permit melting points to be measured in an approximate vacuum (about  $1^{\text{mm}}$  pressure). But it has since been found so much simpler to operate with a neutral or reducing atmosphere in the closed tube passing through the heated zone, that the vacuum furnace has not been used for this work.

The chief disadvantage in the use of a tube of this kind is its effect upon the temperature gradient along the furnace axis. More heat is diverted toward the ends of the furnace and the central constant temperature zone becomes shorter. It offers no difficulty except that greater care must be taken in locating the crucible within the constant temperature region.

The qualities desired in fixed thermometric points for establishing and reproducing a scale are:

(1) Exact reproducibility of the temperature in repeated determinations with the same charge of material and with a different charge independently obtained. This means that the metal or salt must be either perfectly pure or obtainable with a constant amount and kind of impurity.

\* E. T. Allen, in paper of Day and Clement, loc. cit., p. 454.

† See also W. P. White, *Melting Point Determination and Melting Point Methods*, this Journal (4), xxviii, 453 and 474, 1909.

(2) Independence of particular experimental arrangements. The melting point of a metal, for instance, must be sharp and definite enough so that with different kinds of furnaces and different rates of heating, the same temperature will be obtained.

(3) Convenience and safety of manipulation. A melting point which can only be obtained by the use of elaborate experimental arrangements is undesirable, even though it be reproducible and sharp. Furthermore, the substance must not injure the instrument to be calibrated.

(1) *Reproducibility*.—No extensive experiments have been made in the present work to test a large number of samples of different origin. It appeared sufficient to assure ourselves that all of the metals here used are obtainable in such degree of purity, or with such a constant amount of impurity, that the variations in their melting points are well within the limits of error in the scale itself. Waidner and Burgess\* have recently made comparisons of various samples of pure zinc, antimony, and copper, and have found no differences exceeding  $0.3^{\circ}$ .† Our experience has been the same. All of the metals in the present investigation are readily obtainable from the ordinary sources of supply. They have been carefully analyzed in this laboratory by Dr. E. T. Allen, and the results are given in section 6.

(2) *Independence of Experimental Conditions*.—A number of experiments were made to test the effect of different experimental arrangements on the points. Two different furnaces were tried, one 65<sup>mm</sup> inside diameter and 150<sup>mm</sup> long, the other 55<sup>mm</sup> inside diameter and 230<sup>mm</sup> long. The region of constant temperature in the second furnace was longer than in the first and accordingly there was a larger range in which the crucible could be moved about without affecting the temperature. This furnace was used for all work after March 6, 1909. The ultimate test was always the agreement between the melting and freezing points. Any serious disagreement of these two shows that some influence is entering from without.

The results of the study were briefly as follows: (1) The best dimensions for a charge of metal are about 25<sup>mm</sup> diameter by 45<sup>mm</sup> deep. (2) The thermoelement tube should be about 5<sup>mm</sup> above the bottom of the crucible. (3) There is a region within the furnace in which the melting and freezing points agree and are independent of the rate of heating or (within limits) of the depth of immersion of the thermoelement; it is necessary to find this position of the crucible by trial. With this position once determined, the temperature of the zinc, antimony, silver, gold, and copper points can be relied upon

\* Phys. Rev., xxviii, 467, 1909. Bull. Bur. Stds., vi, 149-230, 1909.

† In the case of antimony, this statement applies only to Kahlbaum's metal.

within  $0.2^{\circ}$ . With large charges and facilities for stirring the metal, Waidner and Burgess have found the zinc point to be reproducible in a given furnace, with a given sample, within less than  $0.1^{\circ}$ .

White\* showed that the temperatures of the two silicate points used for the present scale are reproducible within  $1.0^{\circ}$  independently of the dimensions of the furnace or the rate of heating. For a mineral melting point, the charge should be small (about 3 grams), the heat should approach the thermal junction from the side and not from the ends, and a position in the furnace should be found in which the melting point, determined by a bare thermoelement, does not vary with the rate of heating.

The possibility has been several times suggested that the temperature of the thermoelement inside of the tube might possibly be lower by a small constant amount than the temperature of the metal outside of the tube, and that this error might not be brought to light by such experiments as have been described. Several melting and freezing points of copper were, therefore, determined by enclosing the entire thermoelement wire in a thin capillary of silica glass which was slipped over the wire, bent double, and melted down upon the wire at the junction by heating in the oxyhydrogen flame. This was dipped directly into the molten copper to within  $5\text{mm}$  of the bottom, so that there was practically no possibility that the temperature of the junction could be lowered by radiation or conduction upward. The melting point on element D obtained in this way was 10,473 microvolts as compared with 10,473 microvolts in the closed glazed tube. There appears to be no error from this cause.

*Convenience and Safety of Manipulation.*—Zinc and gold are the most convenient of manipulation, as they require no special atmosphere and the temperatures are easily reached. Antimony, silver, and copper require an atmosphere of carbon monoxide and are somewhat less convenient. More care needs to be taken with copper than with silver and antimony because of the considerable effect of a very small amount of oxide. Antimony, silver, gold, and copper were all melted in carbon monoxide, made by dropping formic acid into warm sulphuric acid, and purified by passage through sodium hydroxide, lead nitrate, and sulphuric acid. The lead nitrate was introduced to make certain that no trace of hydrogen sulphide, which might be formed if the acid became too dilute or too warm, could pass into the metal.

The two silicates (diopside and anorthite) and palladium were melted in air. The silicate points are very convenient to

\* Diopside and its Relations to Calcium and Magnesium Metasilicates, this Journal (4), xxvii, p. 5, 1909.

arrange and manipulate, provided the furnace is well insulated so that the temperature can be reached without difficulty. Palladium strains the platinum resistance furnace near to its limit of endurance on account of the high temperature, but has the great convenience of not requiring a reducing atmosphere. Special pains need to be taken, however, in this case, to protect the thermoelement from contamination.

Nickel and cobalt were melted in an atmosphere of hydrogen which was made by electrolysis in a large glass and earthenware generator, and purified by passage through potassium pyrogallate and sulphuric acid. Just before the thermoelement was introduced, the hydrogen was displaced by pure nitrogen drawn from a steel tank in which it was stored under pressure. The supply contained a trace of hydrogen and was, therefore, purified by passing over hot copper oxide and through calcium chloride and sulphuric acid. The extreme lightness of this gas compared with the outside air (especially when it is heated to  $1450^{\circ}$ ) makes necessary special precautions in order to keep out any trace of air. Furthermore, hydrogen always caused contamination in the thermoelement, which was not prevented even when the hydrogen was replaced for a short time during the melting by pure nitrogen. Nickel and cobalt are, therefore, not recommended for frequent use in the calibration of thermoelements, if the two points, diopside and palladium (or diopside and anorthite), give a sufficient calibration for the purpose in hand.

The apparatus used for the melting points of nickel and cobalt is shown in section in fig. 6. The top of the large porcelain tube (Marquardt, glazed outside only) was closed by a sliding cup of brass in which the thermoelement tube and two others for introducing hydrogen were fastened by heating the cup and pouring in molten solder. The porcelain tube extended far enough out of the furnace to keep the brass cup cool. A groove near the base of the cup carried a piece of asbestos cord which made a gas-tight joint with the porcelain tube and permitted the whole to be raised and lowered without moving the crucible or opening the top of the tube. Two diaphragms of Marquardt porcelain above the crucible also prevented any considerable radiation upward to the brass cup.

In zinc, antimony, silver, gold, and copper, the thermoelement was protected by a glazed Marquardt tube of 5<sup>mm</sup> inside and 8<sup>mm</sup> outside diameter. In the case of antimony, the tube was further protected by a thin tube of graphite which fitted into the cover of the crucible. With diopside and anorthite, some contamination from iridium in the furnace may take place, but can be largely prevented by surrounding the tube with pure platinum. A glazed Marquardt tube cannot be used in

this case, for the glaze flows readily at these temperatures and may make its way into the charge. With nickel and cobalt, glazed Marquardt tubes and also pure magnesia tubes of the same size were used, but neither protects the element from contamination. In palladium only the pure magnesia tubes were used.

Zinc, antimony, silver, gold, and copper were melted in graphite crucibles 27<sup>mm</sup> in diameter and 80<sup>mm</sup> deep inside, and 37<sup>mm</sup> in diameter and 100<sup>mm</sup> high outside. The charge of metal was from 45<sup>mm</sup> to 55<sup>mm</sup> deep. Diopside and anorthite were melted in small platinum crucibles 10<sup>mm</sup> in diameter and 18<sup>mm</sup> deep, as described and illustrated in the paper already referred to.\* Nickel was melted in an unglazed Marquardt porcelain crucible, lined with a paste consisting of about 90 per cent  $\text{Al}_2\text{O}_3$  and 10 per cent  $\text{MgO}$ ; and also in a Berlin "pure magnesia" crucible. The charge was about 25<sup>mm</sup> in diameter and 30<sup>mm</sup> deep. Cobalt could not be melted in the alumina lined crucible, as the metal penetrated through the lining and attacked the porcelain. It was, therefore, melted in a "pure magnesia" crucible made by the Königliche Porzellan Manufaktur. The material of these crucibles probably contains a small percentage of silica. Palladium was melted in a crucible made in this laboratory from a specially pure magnesia made by Baker and Adamson. The magnesia was first shrunk by heating to a temperature higher than that at which the crucible was to be used, and was then made into a paste with water and a little magnesium chloride, spun into form, and baked.

Particular details regarding each of the substances used will now be taken up in the order of their temperatures.†

\* W. P. White, this Journal (4), xxviii, 477, 1909.

† See, also, E. T. Allen, in paper of Day and Clement, loc. cit., p. 454.

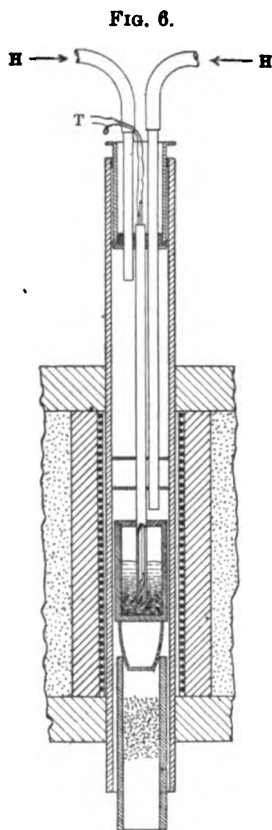


FIG. 6. The furnace in which the standard metal melting points were made, showing the position of the metal with respect to the coil, the thermoelement (T) and the arrangement (H) for maintaining a hydrogen or nitrogen atmosphere.



*Zinc.*—Two samples of “C. P. sticks” were used, both from Eimer and Amend. No appreciable difference could be observed between their melting points. Both melting and freezing points were sharp and measurable to a fraction of a microvolt. Successive readings did not differ by more than one microvolt. The charge was about 200 grams. The analysis has been published.\*

*Antimony.*—Two samples of metal were used, both from Kahlbaum, and no appreciable difference was found between their melting points. An analysis of the first sample is given in section 6. The charge weighed about 150 grams. The melting point is sharp and does not differ from the freezing point by more than one microvolt, provided the undercooling which always precedes solidification does not exceed  $15^{\circ}$ . If the metal is undercooled too far to give an accurate freezing point, the fact is easily recognized by observing that the thermoelement does not return to a sustained constant temperature, but merely rises to a maximum, then falls again. The amount of undercooling is greater the higher the metal has been heated above its melting point after the melting is complete.

*Silver.*—The charge weighed about 260 grams. Only one supply was used, a specially purified sample obtained from the Philadelphia Mint, of which an analysis is given in the previous paper.\* The melting and freezing points were sharp and agreed within one microvolt.

*Gold.*—A new charge of gold was used, weighing 350 grams. This was obtained from Dr. Eckfeldt of the Philadelphia Mint. No analysis was deemed necessary.\*

*Copper.*—The copper was obtained in the form known as “copper drops cooled in hydrogen” (Eimer and Amend). Only one supply was used. The melting and freezing points were not quite as sharp as was the case with silver, but always agreed within 1 microvolt. The temperature is very susceptible to a trace of oxide, which not only lowers the temperature appreciably but makes it more uncertain, so that if a little oxidation has taken place it is recognizable at once. Waidner and Burgess† found that the best commercial electrolytic copper showed an average difference of  $0.2^{\circ}$  in the melting point from the purified copper drops. Charge, about 210 grams.

*Diopside.*—Two samples of diopside were used, one from the preparation of Allen and White‡ and the other made up in 1909 by G. A. Rankin. No appreciable difference was found

\* E. T. Allen, in paper of Day and Clement, p. 454.

† Loc. cit., p. 469 (Phys. Rev.); p. 174 (Bull.).

‡ This Journal (4), xxvii, 1, 1909.

between the melting points. No freezing point can be obtained as the mineral undercools considerably. The charge used was 3 grams.

*Nickel.*—A sample of specially purified electrolytic nickel was obtained from Kahlbaum. The analysis showed less than 0.2 per cent total impurities. Care must be taken in the case of nickel that no oxide forms, as a fairly sharp break can be observed about 10° below the melting point, which may represent the eutectic of nickel and nickel oxide. This break disappeared when the nitrogen was replaced for a few minutes by hydrogen. This lower point may easily be mistaken for the melting point of the metal, and this mistake seems to have occurred in several of the published determinations of the melting point of nickel. Nickel absorbs hydrogen and possibly also nitrogen, and after cooling frequently showed excrescences and signs of "spitting" such as occur with silver in air.

*Cobalt.*—Kahlbaum's purest cobalt was used, containing less than 0.05 per cent total impurity. It was in the form of fine black powder, which was compressed into blocks for convenience in handling. The results obtained were not quite as satisfactory as with nickel on account of the higher temperature and more rapid contamination of the thermoelement. The absorption of gases seemed to be less than was the case with nickel.

Samples of Eimer and Amend's "98 to 99 per cent pure" nickel and cobalt were also tried. The difference between the two samples of nickel was not greater than the uncertainty in the melting point caused by contamination of the thermoelement. The "98-99 per cent pure" cobalt melted about 3.5° lower than the pure sample. Since the impurities in nickel are usually chiefly iron and cobalt, and those of cobalt are chiefly iron and nickel, and since the melting points of all three are close together, the melting points of the slightly impure metals can not be expected to lie far from those of the pure metals.

*Anorthite.*—Only one preparation of anorthite was used, made by G. A. Rankin 1909. The charge was about 3 grams. The melting point is not quite as sharp as that of diopside. Only the melting point can be obtained, as the mineral undercools considerably; it may even cool to glass without crystallization, in which case of course no melting point will be obtained on the following heating.

*Palladium.*—About 350 grams of pure palladium, in the form of sheet, was loaned to us by Dr. Heraeus. It melts and freezes quite sharply, making an excellent substance for a fixed thermometric point. The greatest uncertainty is caused by the vaporization of the metal and consequent contamination of the thermoelement wire. The charge used weighed 128-210 grams

In addition to the fixed points which have just been described, two other metal melting points, cadmium and aluminum, were incidentally determined. Only one measurement of the cadmium point was made on the gas thermometer, and this chiefly for the purpose of checking the extrapolation below the zinc point. The conditions of melting were the same as for zinc. The sample was obtained from Eimer and Amend, and its analysis has been given in a paper by Day and Allen.\* The charge weighed 215 grams.

A sample of pure aluminum obtained from the Aluminum Company of America was melted in a graphite crucible of the usual size in an atmosphere of carbon monoxide. On account of the sensitiveness of aluminum to silicon contamination, the tube carrying the thermoelement was also provided with a thin protecting cover of graphite so that the metal came in contact only with pure graphite. The freezing point was sharp and constant. The melting point was less sharp but lay within  $0.5^{\circ}$  of the freezing point.

The effect on the final temperature of all the errors and corrections which have been discussed in this section, is shown in summarized form in Table IV.

The figures of Table IV serve to emphasize the statements already made, that the greatest present uncertainty in the high temperature gas scale arises from the lack of uniformity in an air bath, which not only leads to uncertainty as to what is the true temperature of the gas in the bulb, but also to errors in the transference by the thermoelement. The next largest uncertainty, due to the limitations of the materials used for fixed points, is not directly chargeable to the gas thermometer. In this connection, considerably more work needs to be done on the high thermometric points, comparable in thoroughness to the work in low temperature thermometry of Richards, Dickinson, and others, on the sodium sulphate transition point.

#### 4. *Experimental Data and Calculated Results.*

*A. Expansion Coefficient.*—In Table V are given the experimental data on the expansion coefficients of the alloy 80 per cent platinum, 20 per cent rhodium. In the first column is given the date of the series, in the second and third columns the readings of the thermoelements at the middle of the bar, corrected for zero error and the temperature of the cadmium cell. The 12 other readings taken with each element at each temperature at different points along the bar cannot be given here, but the fourth and fifth columns contain the readings of the thermoelement corrected to represent the integrated tem-

\* Arthur L. Day and E. T. Allen, *Phys. Rev.*, xix, 180, 1904.

TABLE IV.—*Estimated Errors and their Effect on the Value of  $t$ .*

Quantity affected	Source of error	Amount of error		Effect on $t$	
		at 400°	at 1500°	at 400°	at 1500°
(A) Temperature of gas	Temperature differences over bulb surface	2 mv.	5 mv.	$\pm 0.2^\circ$	$\pm 0.4^\circ$
	Variability	0	1 mv.	0	$\pm 0.1^\circ$
(B) $p_0$	Reference point	0.02 mm.	0.02 mm.	$\pm 0.04^\circ$	$\pm 0.15^\circ$
"	Manometer setting	0.02 mm.	0.02 mm.	$\pm 0.04^\circ$	$\pm 0.15^\circ$
"	Scale corrections	0.01 mm.	0.01 mm.	$\pm 0.02^\circ$	$\pm 0.07^\circ$
"	Temperature of mercury	0.05 mm.	0.05 mm.	$\pm 0.10^\circ$	$\pm 0.38^\circ$
"	Barometer setting	0.03 mm.	0.03 mm.	$\pm 0.06^\circ$	$\pm 0.23^\circ$
"	Temperature of barometer	0.05 mm.	0.05 mm.	$\pm 0.10^\circ$	$\pm 0.38^\circ$
"	Variations in $p_0$	0	0.05 mm.	0	0 to $\pm 0.3$
$p$	Reference point	0.02 mm.	0.02 mm.	$\pm 0.02^\circ$	0
"	Manometer setting	0.02 mm.	0.02 mm.	$\pm 0.02^\circ$	0
"	Scale corrections	0.02 mm.	0.02 mm.	$\pm 0.02^\circ$	0
"	Temperature of mercury	0.07 mm.	0.20 mm.	$\pm 0.07^\circ$	$\pm 0.05^\circ$
"	Barometer setting	0.03 mm.	0.03 mm.	$\pm 0.03^\circ$	$\pm 0.01^\circ$
"	Barometer temperature	0.05 mm.	0.05 mm.	$\pm 0.05^\circ$	$\pm 0.01^\circ$
"	Unheated { $v_1$ space } $t_1$	0.020 cc. 0.5–50°	0.020 cc. 0.5–100°	$\pm 0.07^\circ$ $\pm 0.01^\circ$	$\pm 0.5^\circ$ $\pm 0.1^\circ$
$\beta$	Temperature Expansion	1.0°	2.0°	$\pm 0.02^\circ$	$\pm 0.11^\circ$
"	Hysteresis in expansion	0.005 mm.	0.008 mm.	$\pm 0.02^\circ$	$\pm 0.09^\circ$
"		0.01 mm.	0.01 mm.	$\pm 0.04^\circ$	$\pm 0.10^\circ$
(C) E.M.F.	Instrumental correction	1 mv.	2 mv.	$\pm 0.1^\circ$	$\pm 0.2^\circ$
"	Contamination	0	0–12 mv.	0	0 to $+1.0^\circ$
"	Integration over bulb	3 mv.	12 mv.	$\pm 0.3^\circ$	$\pm 1.0^\circ$
(D) Fixed points	Instrumental corrections	1 mv.	2 mv.	$\pm 0.1^\circ$	$\pm 0.2^\circ$
"	Contamination	0	0–10 mv.	0	0 to $-1.0^\circ$
"	Variation in given charge	Specific 1–10 mv.		Specific 0.1–1.0°	
"	Variation between different charges	Specific 1–20 mv.		Specific 0.1–2.0°	

perature along the bar. For convenience, the integration was made in terms of microvolts instead of degrees. The sixth and seventh columns contain the temperatures corresponding

TABLE V.—*Observations of Expansion Coefficient,  $\beta$ .*

Date	Thermoelements				Temperature			Expansion from 0°	
	W	Z	W cor.	Z cor.	by W	by Z	Mean	mm on 500 mm	10 $\beta$
1908									
Sept. 21	2261	2251	2312	2298	301.4°	301.4°	301.4°	1.404	9.32
	3197	3187	3273	3258	404.6	405.4	405.0	1.912	9.44
	4169	4153	4257	4237	506.0	507.1	506.6	2.434	9.61
	5157	5140	5237	5212	608.9	605.1	604.5	2.950	9.76
	6197	6178	6286	6262	705.4	707.2	706.3	3.500	9.91
	7264	7238	7362	7333	806.2	807.8	807.0	4.064	10.07
	8361	8335	8457	8420	905.9	906.7	906.3	4.640	10.24
	9509	9470	9599	9552	1006.9	1006.8	1006.8	5.241	10.41
	10662	10611	10733	10675	1104.5	1103.4	1104.0	5.828	10.56
	11963	11896	12018	11921	1215.3	1210.2	1212.8	6.469	10.67
Sept. 25	1817	1801	1848	1831	248.7	248.4	248.6	1.154	9.28
	2756	2735	2791	2768	353.4	352.9	353.2	1.666	9.43
	3699	3674	3726	3702	451.8	452.0	451.9	2.158	9.55
	4686	4655	4691	4662	549.7	550.3	550.0	2.668	9.70
	5711	5679	5691	5660	648.2	649.2	648.7	3.191	9.84
	6820	6788	6772	6742	751.2	752.6	751.9	3.757	9.99
	7847	7813	7754	7720	842.2	843.2	842.7	4.262	10.11
	8980	8945	8845	8809	940.8	941.4	941.1	4.827	10.26
	10140	10102	9939	9901	1036.4	1037.0	1036.8	5.403	10.42
	11368	11327	11109	11063	1136.9	1136.4	1136.7	6.012	10.58
Oct. 3	2291	2272	2302	2283	300.3	299.8	300.1	1.384	9.22
	3228	3205	3250	3228	402.2	402.2	402.2	1.899	9.44
	4208	4181	4243	4215	504.6	504.9	504.8	2.432	9.63
	5205	5175	5247	5216	604.8	605.5	605.2	2.964	9.79
	6238	6206	6281	6249	704.9	705.9	705.4	3.511	9.95
	7297	7263	7342	7309	804.4	805.5	805.0	4.069	10.11
	8401	8365	8446	8408	904.9	905.6	905.3	4.644	10.26
	9536	9497	9576	9534	1004.9	1005.2	1005.1	5.231	10.41
	10675	10647	10710	10670	1102.6	1103.0	1102.8	5.830	10.57
	11884	11857	11926	11875	1207.5	1206.2	1206.8	6.466	10.71
Oct. 29	8419	8377	8366	8324	897.4	898.0	897.7	4.618	10.29
	9551	9507	9436	9392	992.6	992.8	992.7	5.169	10.41
	10706	10663	10539	10496	1088.0	1088.2	1088.1	5.732	10.57
	11884	11849	11786	11751	1195.6	1195.7	1195.7	6.401	10.70
	13137	13104	13134	13101	1309.9	1309.8	1309.9	7.154	10.92
1909	W	D	W cor.	D cor.	by W	by D			
Oct. 13	2304	2301	2235	2232	293.0	293.0	293.0	1.352	9.23
	6222	6217	6180	6175	695.2	695.9	695.6	3.452	9.92
	9501	9494	9493	9486	997.6	998.1	997.9	5.190	10.40
Oct. 14	9540	9536	9542	9544	1001.9	1003.1	1002.5	5.200	10.37
	10666	10663	10690	10691	1101.9	1102.5	1102.2	5.811	10.54
	11839	11836	11783	11783	1195.4	1195.7	1195.6	6.410	10.72
	12998	12993	13121	13120	1308.9	1308.6	1308.8	7.156	10.93
	14183	14170	14390	14372	1413.4	1411.6	1412.5	7.882	11.09

to the readings in columns 4 and 5, and the eighth column, the mean of these two temperatures. The micrometer readings are not given, but in column 9 will be found the expansions reduced to millimeters for that portion of the bar lying between the 0 and 50<sup>cm</sup> marks on the ends. Each of these represents the mean of eight settings at each end of the bar. In the last column are given the values of the mean expansion coefficient from 0°, calculated by dividing the expansion by the length at 0 and by the temperature.

For convenience of comparison, the values of  $\beta$  at the nearest round temperatures were interpolated linearly between the observations in each series, and the results are given in Table VI. Values interpolated between these values are given in parentheses.

TABLE VI.—*Values of  $10^6 \beta$  at Round Temperatures for the alloy 80 Pt, 20 Rh.*

Temp.	21 Sept. 1908	25 Sept. 1908	8 Oct. 1908	29 Oct. 1908	18 Oct. 1909	14 Oct. 1909	Mean
250		9.28					9.28
300	9.31	(9.36)	9.22		9.24		9.28
350	(9.37)	9.43	(9.33)		(9.38)		9.36
400	9.43	(9.49)	9.44		(9.41)		9.44
450	(9.52)	9.55	(9.53)		(9.50)		9.52
500	9.60	(9.62)	9.62		(9.58)		9.61
550	(9.67)	9.70	(9.71)		(9.67)		9.69
600	9.75	(9.77)	9.79		(9.76)		9.77
650	(9.83)	9.84	(9.86)		(9.84)		9.84
700	9.90	(9.92)	9.94		9.98		9.92
750	(9.98)	9.99	(10.02)		(10.01)		10.00
800	10.06	10.06	10.10		(10.09)		10.08
850	(10.14)	10.12	(10.17)		(10.16)		10.15
900	10.23	(10.20)	10.25	10.29	(10.24)		10.24
950	(10.31)	10.27	(10.32)	(10.36)	(10.32)		10.32
1000	10.40	(10.36)	10.40	10.42	10.40	10.37	10.39
1050	(10.47)	10.44	(10.48)	(10.50)		(10.45)	10.47
1100	10.55	(10.52)	10.57	10.59		10.54	10.55
1150	(10.60)	10.60	(10.64)	(10.65)		(10.63)	10.62
1200	10.65	(10.67)	10.71	10.71		10.73	10.69
1250				(10.81)		(10.82)	10.81
1300				10.90		10.92	10.91
1350				(10.99)		(10.99)	10.99
1400						11.07	11.07
1450							(11.15)
1500							(11.23)

The table shows that the percentage error at 300° is greater than that at 1200° and above, probably on account of the larger effect of the hysteresis in the expansion and contraction, already discussed on page 114. The agreement of the results is very satisfactory, particularly in view of the fact that each

series represents an entirely different curve of temperature variation along the bar. In some cases the temperatures at the ends were lower than at the middle, in others higher than at the middle, and in one series one end was higher and the other lower. The mean of all, therefore, probably eliminates any error which might arise from variation of temperature along the bar.

The results are represented within the limits of error by the straight line equation :

$$10^{\circ}\beta = 8.79 + 0.00161t.$$

This may be compared here with the expansion coefficients between 300° and 1000° determined by the authors for the 10 per cent iridium alloy,\* and of Holborn and Day† for the 20 per cent iridium alloy and for pure platinum :

$$80 \text{ Pt. } 20 \text{ Ir. } 10^{\circ}\beta = 8.20 + 0.00142t$$

$$90 \text{ Pt. } 10 \text{ Ir. } 10^{\circ}\beta = 8.84 + 0.00131t$$

$$\text{Pt. } 10^{\circ}\beta = 8.87 + 0.00132t.$$

*B. Gas Thermometer Data and Fixed Points.*—In Table VII are given the observed gas thermometer data.‡ In the first column is the date of the measurement. The measurements are numbered chronologically in the second column for convenience of reference. In the third column is the measured pressure,  $p'$  (or  $p_o'$ ) in millimeters of mercury at 0°, corrected as described on pages 107 and 108. The application of the correction for unheated space (see p. 108) gives the pressure  $p$  (or  $p_o$ ) which is found in the fourth column. In the fifth column is the value of the temperature,  $t$ , calculated by formula (5) on page 101. In column 6 are given the readings of the standard thermoelements in microvolts, and in column 7 the positions of these elements on the bulb; for the significance of these figures see fig. 1 and note on page 104. In the last column are given the other elements which were used on the bulb, together with their positions designated in the same way. The italicized letters represent single platinum wires instead of thermoelements.

A few measurements in which the value of  $p_o$  changed by more than 0.1 per cent have been omitted; their position is shown by the absence of their corresponding serial numbers.

\* Published in paper of Day and Clement, loc. cit, pp. 425-441.

† This Journal (4), xi, 374, 1901.

‡ For the measurements in the table, seven furnaces were employed, using three supplies of platinum wire of about 400 grams each. One of these furnaces was wound on the outside, the other six on the inside of the tube. It was possible to rewind the wire at least once after the furnace had burned out. Failure always occurred several cms. away from the bulb in the end portions of the furnace, which, in order to secure uniformity of temperature over the bulb, had to be considerably superheated. Only one measurement was made at the palladium point, as this one rendered the furnace unfit for further use; the conditions of this measurement, were, however, perfect.

TABLE VII—*Observed Gas-Thermometer Data.*

Date	No.	$p'$ (or $p_0$ )	$p$ (or $p_0$ )	$t$	Standard Elements	Position	Other elements and positions
1908							
GAS FILLING No. 1							
30 Nov.	1	217·65	217·63	0°	-----		
"	2	1037·77	1042·72	1079·87	W10443 } X 10491 }	4 8	Z (1), S (9)
1 Dec.	3	217·45	217·43	0	-----		
2 Dec.	5	217·10	217·08	0	-----		
3 Dec.	6	948·81	952·84	960·59	W 9061 } X 9100 }	4 8	Z (1), S (9)
4 Dec.	7	217·12	217·10	0	-----		
16 Dec.	8	217·08	217·06	0	-----		
17 Dec.	9	1038·50	1043·48	1083·61	W10483 } X 10555 }	4 8	Z (1), S (9)
18 Dec.	10	217·18	217·16	0	-----		
19 Dec.	11	1038·57	1043·56	1083·77	W10473 } X 10512 }	4 8	Z (1), S (9)
21 Dec.	12	217·06	217·04	0	-----		
23 Dec.	15	217·49	217·47	0	-----		
24 Dec.	16	1242·38	1249·71	1365·71	A 13866 } X ----- }	4 8	Y (1), S (9)
28 Dec.	17	217·57	217·55	0	-----		
1909							
22 Jan.	18	1039·78	1044·74	1082·84	A 10502 } Y 10612 }	4 8	Z (9), B (1·3) W (2·3), S (6·7) X (7·8)
"	19	1038·82	1043·79	1081·87	A 10506 } Y 10584 }	4 8	Do.
"	20	1037·85	1042·83	1080·89	A 10498 } Y 10555 }	4 8	Do.
23 Jan.	21	217·36	217·34	0	-----		
25 Jan.	22	543·01	544·07	418·40	A 3414 } Y 3436 }	4·5 8	Do.
"	23	542·27	543·82	417·43	A 3408 } Y 3435 }	4·5 8	Do.
26 Jan.	24	703·78	705·61	629·80	A 5510 } Y 5550 }	4·5 8	Do.
"	25	702·64	704·67	628·34	A 5501 } Y 5529 }	4·5 8	Do.
"	26	949·56	953·63	960·22	A 9090 } Y 9159 }	4·5 8	Do.
"	27	948·15	952·23	958·41	A 9075 } Y 9119 }	4·5 8	Do.
"	28	1039·03	1044·05	1083·01	A 10515 } Y 10598 }	4·5 8	Do.
"	29	1037·92	1042·93	1081·56	A 10505 } Y 10556 }	4·5 8	Do.
27 Jan.	30	217·33	217·31	0°	-----		
28 Jan.	31	542·87	543·92	418·30	A 3410 } Y 3436 }	4·5 8	Do.
"	32	542·07	543·11	417·25	A 3404 } Y 3425 }	4·5 8	Do.
"	33	704·06	706·07	630·21	A 5514 } Y 5553 }	4·5 8	Do.



TABLE VII—(Continued)

Date	No.	$p'$ (or $p_0'$ )	$p$ (or $p_0$ )	$t$	Standard Elements	Position	Other elements and positions
28 Jan.	34	703·35	705·37	629·31	A 5510 } Y 5537 }	4·5 8	Z (9), B (1·3), W (2·3), S (6·7) X (7·3)
"	35	948·96	953·05	959·46	A 9087 } Y 9142 }	4·5 8	Do.
"	36	949·86	953·97	960·69	A 9098 } Y 9163 }	4·5 8	Do.
"	37	1038·50	1043·57	1082·23	A 10511 } Y 10576 }	4·5 8	Do.
"	38	1038·99	1044·06	1082·90	A 10512 } Y 10585 }	4·5 8	Do.
"	39	1039·61	1044·68	1083·68	A 10509 } Y 10617 }	4·5 8	Do.
29 Jan.	40	217·37	217·35	0°	-----		
"	41	949·32	953·38	959·78	A 9086 } Y 9156 }	4·5 8	Do.
"	42	948·58	952·66	958·81	A 9085 } Y 9131 }	4·5 8	Do.
"	43	1039·29	1044·34	1083·15	A 10515 } Y 10595 }	4·5 8	Do.
"	44	1038·49	1043·56	1082·09	A 10511 } Y 10568 }	4·5 8	Do.
"	45	1039·63	1044·71	1083·58	A 10508 } Y 10617 }	4·5 8	Do.
30 Jan.	46	217·39	217·37	0	-----		
GAS FILLING No. 2							
18 Feb.	47	346·74	346·70	0	-----		
22 Feb.	48	346·78	346·74	0	-----		
23 Feb.	49	745·09	746·19	319·55	A 2487 } D 2483 } Z 2462 }	4·5 4·5 8	W (1·3), B (2·2), X (6·2), S (7·3), Y (12)
"	50	866·47	868·15	418·40	A 3414 } D 3406 } Z 3385 }	4·5 4·5 8	Do.
"	51	995·97	998·38	524·71	A 4451 } D 4439 } Z 4413 }	4·5 4·5 8	Do.
"	52	1122·39	1125·61	629·37	A 5510 } D 5495 } Z 5463 }	4·5 4·5 8	Do.
24 Feb.	53	346·67	346·63	0	-----		
26 Feb.	59	346·24	346·20	0	-----		
"	60	1657·03	1665·07	1083·17	A 10508 } D 10473 } Z 10422 }	4·5 4·5 8	W (3·3), B (2·2), X (6·2), S (7·2), Y (12)
27 Feb.	61	346·45	346·41	0	-----		
1 Mar.	62	1388·84	1394·13	853·76	A 7895 } D 7869 } Z 7829 }	4·5 4·5 8	B (3·2), W (2·3), X (6·2), S (7·2), Y (12)
"	63	1513·67	1520·20	960·29	A 9086 } D 9055 } Z 9010 }	4·5 4·5 8	Do.
"	64	1632·03	1639·78	1062·15	A 10265 } D 10229 } Z 10178 }	4·5 4·5 8	Do.

TABLE VII—(Continued)

Date	No.	$p'$ (or $p_0'$ )	$p$ (or $p_0$ )	$t$	Standard Elements	Position	Other elements and positions
1 Mar.	65	1655.77	1663.81	1082.84	A 10511 D 10474 Z 10420	4.5 4.5 8	B (3.2), W (2.3), X (6.2), S (7.2), Y (12)
2 Mar.	66	346.20	346.17	0	-----		
3 Mar.	67	1386.28	1391.55	852.44	A 7885 D 7861 Z 7820	4.5 4.5 8	W (3.3), B (2.2) X (6.2), S (7.2) Z (8), Y (12)
"	68	1511.95	1518.48	959.81	A 9088 D 9059 Z 9018	4.5 4.5 8	Do.
"	69	1628.71	1636.46	1060.24	A 10257 D 10221 Z 10169	4.5 4.5 8	Do.
"	70	1654.46	1662.50	1082.73	A 10511 D 10478 Z 10444	4.5 4.5 8	Do.
5 Mar.	71	345.98	345.94	0	-----		
GAS FILLING No. 3							
4 June	72	345.31	345.27	0	-----		
"	73	861.67	862.94	417.07	A 3403 E 3419 F 3414 G 3416 Z 3370	4.1 4.3 4.5 4.7 8	Y (1), $\alpha$ (2.4), b (6.4)
"	74	1118.50	1120.83	629.11	A 5516 E 5535 F 5528 G 5529 Z 5461	4.1 4.3 4.5 4.7 8	Do.
5 June	75	345.31	345.27	0	-----		
"	76	1510.50	1515.27	959.77	A 9090 E 9114 F 9099 G 9108 Z 9002	4.1 4.3 4.5 4.7 8	Do.
"	77	1628.08	1633.64	1060.53	A 10258 E 10285 F 10266 G 10279 Z 10181	4.1 4.3 4.5 4.7 8	Do.
"	78	1652.36	1658.10	1081.28	A 10503 E 10529 F 10510 G 10523 Z 10404	4.1 4.3 4.5 4.7 8	Do.
7 June	79	345.50	345.46	0	-----		
10 June	80	345.52	345.48	0	-----		
18 June	81	1512.96	1517.69	961.21	F 9129 E 9128 A 9080 G 9122 Z 9015	4.1 4.3 4.5 4.7 8	$\alpha$ (1), b (2.4), c (6.4), e (7.3)
"	82	1630.94	1636.53	1062.53	F 10299 E 10300 A 10252 G 10292 Z 10181	4.1 4.3 4.5 4.7 8	Do.

TABLE VII—(Continued)

Date	No.	$p'(\text{or } p_0')$	$p(\text{or } p_0)$	$t$	Standard Elements	Position	Other elements and positions
18 June	83	1653·61	1659·87	1082·14	F 10584 E 10534 A 10487 G 10526 Z 10408 F 10536 E 10534 A 10485 G 10525 Z 10426	4·1 4·3 4·5 4·7 8 4·1 4·3 4·5 4·7 8	$a(1), b(2·4)$ $c(6·4), e(7·3)$  Do.
"	84	1654·51	1660·27	1082·91			
19 June	85	345·51	345·47	0	----		
GAS FILLING No. 8a							
19 June	86	219·78	219·71	0	F 5520 E 5520 A 5484 G 5516 Z 5437 F 9139 E 9136 A 9089 G 9131 Z 9036 F 10540 E 10538 A 10490 G 10531 Z 10428	4·1 4·3 4·5 4·7 8 4·1 4·3 4·5 4·7 8 4·1 4·3 4·5 4·7 8	$a(1), e(2·3)$ $c(6·3), f(7·3)$  Do.  Do.
"	87	710·84	711·88	627·61			
"	88	962·21	965·23	961·71			
"	89	1051·74	1055·41	1082·75			
21 June	90	219·74	219·72	0	----		
22 June	92	220·65	220·63	0	----		
24 June	93	220·62	220·59	0	----		
25 June	95	220·56	220·53	0	----		
2 July	96	1283·36	1288·82	1391·97	H 14251 E 14227 F 14222 G 14245 Z 14121 H 14282 E 14247 F 14241 G 14274 Z 14156	4·1 4·3 4·5 4·7 8 4·1 4·3 4·5 4·7 8	Do.  Do.
3 July	98	221·02	220·99	0	----		
"	99	1281·97	1287·45	1393·34	H 14213 E 14214 F 14196 G 14216 Z 14099 H 14264 E 14242 F 14235 G 14259 Z 14156	4·1 4·3 4·5 4·7 8 4·1 4·3 4·5 4·7 8	Do.  Do.
6 July	101	220·62	220·60	0	----		

TABLE VII—(Continued)

Date	No.	$p'$ (or $p_0'$ )	$p$ (or $p_0$ )	$t$	Standard Elements	Position	Other elements and positions
GAS FILLING No. 4							
8 July	102	216·81	216·79	0	H 14235	4·1	$a$ (1), $e$ (2·3) $c$ (6·3), $f$ (7·3)
"	103	1261·35	1266·80	1891·15	E 14216	4·8	
					F 14209	4·5	
					G 14222	4·7	
					Z 14124	8	
					H 14249	4·1	Do.
"	104	1263·13	1268·59	1893·55	E 14229	4·3	
					F 14199	4·5	
					G 14236	4·7	
					Z 14155	8	
					H 14251	4·1	Do.
9 July	105	217·36	217·33	0	E 14236	4·3	
"	106	1261·71	1267·15	1891·64	F 14233	4·5	
					G 14241	4·7	
					Z 14123	8	
					H 14240	4·1	Do.
					E 14236	4·3	
"	107	1263·01	1268·46	1893·44	F 14225	4·5	
					G 14238	4·7	
					Z 14152	0	
					H 15019	4·1	Do.
10 July	108	217·35	217·33	0	E 15020	4·3	
"	109	1306·60	1312·52	1455·37	F ----	4·5	
					G ----	4·7	
					Z 14903	8	
					H 14978	4·1	Do.
					E 14980	4·3	
12 July	110	217·36	217·34	0	F ----	4·5	
					G ----	4·7	
					Z 14867	8	
					H 14980	4·1	Do.
					E 14960	4·3	
"	111	1305·53	1311·35	1453·52	F 14947	4·5	
					G ----	4·7	
					Z 14872	8	
					H ----	4·1	Do.
					E 15389	4·3	
13 July	113	217·40	217·38	0	F 15374	4·5	$a$ (1), $c$ (2·3) $e$ (6·7), $f$ (7·3)
10 Sept.	114	217·38	217·36	0	G ----	4·7	
11 Sept.	115	1328·68	1334·79	1484·70	A 15357	8	
					H ----	4·1	
					E 15411	4·3	
					F 15417	4·5	
					G 15418	4·7	Do.
"	116	1332·18	1338·32	1489·60	A 15421	8	
					-----	-----	
					H ----	4·1	
					E 15411	4·3	
					F 15417	4·5	
13 Sept.	117	217·62	217·60	0	-----	-----	

TABLE VII—(Continued)

Date	No.	$p'(\text{or } p_o')$	$p(\text{or } p_o)$	$t$	Standard Elements	Position	Other elements and positions
15 Sept.	118	1329.92	1336.03	1487.86	H ----- E 15391 F 15389 G 15399 A 15382	4.1 4.3 4.5 4.7 8	$\alpha$ (1), $\epsilon$ (2.3) $\epsilon$ (6.7) $f$ (7.3)
16 Sept.	119	217.51	217.49	0	H ----- E 15386 F 15376 G 15368 A 15379	4.1 4.3 4.5 4.7 8	Do.
17 Sept.	120	1329.68	1335.78	1486.95	H ----- E 15397 F 15396 G 15389 A 15412	4.1 4.3 4.5 4.7 8	Do.
"	121	1331.40	1337.51	1489.34	H ----- E 14991 F 14996 G 14957 A 14982	4.1 4.3 4.5 4.7 8	Do.
18 Sept.	122	217.52	217.50	0	H ----- E 14979 F 14984 G 14952 A 14996	4.1 4.3 4.5 4.7 8	Do.
21 Sept.	123	1306.75	1312.72	1454.83	H ----- E 10618 F 10626 G 10616 C 10567	4.1 4.3 4.5 4.7 8	$\alpha$ (1.5), J (2.4) $\epsilon$ (6.2), $\epsilon$ (7.2)
"	124	1307.28	1313.25	1455.60	H ----- E 12002 F 12003 G 12010 C 11914	4.1 4.3 4.5 4.7 8	Do.
22 Sept.	125	217.45	217.43	0	H ----- E 13106 F 13112 G 13115 C 13007	4.1 4.3 4.5 4.7 8	Do.
27 Nov.*	126	1045.80	1049.49	1090.59	H ----- E 14246 F 14250 G 14248 C 14146	4.1 4.3 4.5 4.7 8	Do.
29 Nov.	127	217.28	217.26	0	H ----- E 11940 F 11951 G 11949 C 11887	4.1 4.3 4.5 4.7 8	$\alpha$ (1), J (2.3), $\epsilon$ (6.2), $\epsilon$ (7.1)
9 Dec.	128	1129.52	1133.91	1206.63	H ----- E 11946 F 11951 G 11949 C 11887	4.1 4.3 4.5 4.7 8	
"	129	1194.81	1199.74	1298.01	H ----- E 11946 F 11951 G 11949 C 11887	4.1 4.3 4.5 4.7 8	
"	130	1261.16	1266.68	1391.45	H ----- E 11946 F 11951 G 11949 C 11887	4.1 4.3 4.5 4.7 8	
10 Dec.	131	217.30	217.28	0	H ----- E 11946 F 11951 G 11949 C 11887	4.1 4.3 4.5 4.7 8	
20 Dec.	132	1125.92	1130.29	1201.50	H ----- E 11946 F 11951 G 11949 C 11887	4.1 4.3 4.5 4.7 8	

\* Outside-wound furnace. See page 106.

TABLE VII—(Concluded)

Date	No.	$p'$ (or $p_0'$ )	$p$ (or $p_0$ )	$t$	Standard Elements	Position	Other elements and positions
20 Dec.	133	1302.40	1308.33	1450.03	H 14950	4.1	$\alpha$ (1), J (2.3) $c$ (6.2), $e$ (7.1)
					E 14958	4.8	
					F 14962	4.5	
					G 14955	4.7	Do.
					C 14882	8	
					H 16156	4.1	
"	134	1372.16	1378.78	1550.15	E 16160	4.8	
					F 16170	4.5	
					G 16148	4.7	
21 Dec.	135	217.29	217.27	0	C 16075	8	

(Continued from p. 132.)

The melting and freezing points of the metals and salts, measured with the various thermoelements used during the investigation, as well as the frequent comparisons of thermoelements with each other, are too numerous to be published here, especially as they are practically all summarized in Table VIII.

Table VIII contains the final temperature of each thermometric point studied. In the first column is the number of the experiment corresponding to that in Table VII. In the second column is the correction in degrees to be applied to each of the thermoelement readings on the *outside* of the bulb, integrated from the readings of the auxiliary elements as described on page 119; in the third column is given the corresponding correction in microvolts. In the fourth column are the readings of the standard elements on the *outside* of the bulb, corrected as above mentioned. In the fifth column are the readings of the same thermoelements at the fixed point in question, as obtained in the melting or freezing of metal or salt; these figures usually represent the mean of a considerable number of determinations.

In the sixth and seventh columns are the corresponding figures for the element *inside* of the bulb. In this case, however, no correction has been applied to the reading of the element, since, being located practically at the center of the bulb, it might be expected to represent the mean temperature of the entire volume of the bulb.

In the eighth and ninth columns are the temperatures of the fixed points derived from the preceding four columns. In the last column is given the weight assigned to each measurement. In assigning these weights the number of standard thermoelements used, the amount of variation in  $p_0$ , and other incidental variables were taken into consideration.

As has been pointed out on page 116, the relative weights to be assigned to the inside and outside elements are different at

different temperatures; (1) on account of the difference in contamination, and (2) on account of the fact that the inside element is subject to the influence of conduction and radiation from below. The weights assigned were as follows:

Temperatures	Outside Element	Inside Element
400–1100°	3	1
1100–1300°	2	1
1300–1550°	1	1

The final weighted mean of the inside and outside elements is given at the head of each section of the table.

In the last section of the table are given various points which were determined to aid in interpolating between the fixed points by means of the thermoelement.

The only comment which need be made here on the data in Table VIII concerns the figures given under the heading "copper point." In this section of the table, the values derived at the two different initial pressures (217–221<sup>mm</sup> and 346–347<sup>mm</sup>) are quoted separately in order to bring out the fact that the difference between the temperatures obtained from these two pressures is less than the experimental error. In the other sections of the table the data obtained at the two pressures are not separately arranged. Above the copper point only the low pressure was used, as the high pressure would have exceeded the range of the manometer.

The significance of the comparison between the inside-and outside-wound furnaces, which appears in the first half of the section on the copper point, has been commented on elsewhere (see p. 106).

#### 5. Interpolation Between the Fixed Points.

The preparation of formulae to represent the relation between the temperature defined by the gas thermometer and the electromotive force of a thermoelement has always been a cause of considerable dissatisfaction, both to the maker and the user. The chief reason for this is perhaps the fact that the formulae used have been applicable only to limited portions of the curve and have therefore given no suggestion of physical significance. In the Reichsanstalt publication\* the data extended from 300° to 1100° and included several good fixed points (melting points of pure metals) between which no interpolation, however rough, could go far astray. Accordingly, in so far as interpolation was concerned, but little attention required to be given to the formulation of this relation. It was sufficient that a simple formula of the form

$$E = -a + bt + ct^2$$

could be made to represent the observations between 300° and 1100° within the limits of the errors of observation.

\* Holborn and Day, 1900, loc. cit.

TABLE VIII—Temperatures of the Fixed Points.

Exp. No.	Integrated correction to outside elements		Standard Elements				Temperature		Weight
			Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	By Outside Element	By Inside Element	
Degr's M.V.									
Zinc Point. 418·2°									
22	0·0°	0	A 3414	3411	Y 3436	3436	418·1°	418·4°	2
23	-0·3	-3	A 3405	3410·5	Y 3445	3435	418·0	418·4	2
31	0·0	0	A 3410	3410·5	Y 3436	3435	418·3	418·2	2
32	-0·2	-2	A 3402	3410	Y 3425	3434	418·0	418·1	2
50	-0·1	-0·5	A 3413	3411	Z 3384·5	3382	418·2	418·2	3
			D 3405·5	3406			418·4		
73	-0·2	-2					418·3		
			A 3401	3418·5			418·4		
			E 3417	3429			418·3		
			F 3412	3429			418·8		
			G 3414	3429	Z 3370	3382	418·6		
							418·5	418·3	4
Weighted Mean,							418·2°	418·3°	
Antimony Point. 629·2°									
24	-0·1	-1	A 5509	5503	Y 5550	5546	629·2°	629·4°	2
25	-0·5	-5	A 5496	5503	Y 5529	5545	629·0	629·9	2
33	-0·1	-1	A 5513	5503	Y 5553	5544	629·2	629·3	2
34	-0·5	-5	A 5505	5503	Y 5537	5543	629·1	629·9	2
52	-0·5	-5	A 5505	5503	Z 5463	5460	629·6	629·1	2
			D 5490	5492			629·2		
74	-0·2	-2					629·4		
			A 5514	5504			628·2		
			E 5533	5530			628·8		
			F 5526	5530			629·5		
			G 5527	5530	Z 5461	5461	629·4		
87	-0·3	-3					629·0	629·1	4
			F 5517	5530			628·9		
			E 5517	5530			628·9		
			A 5481	5504			629·9		
			G 5513	5530	Z 5437	5461	629·3		
							629·2	629·9	4
Weighted Mean,							629·1°	629·5°	
Silver Point. 960·0°									
6	+0·8	+9	W 9070	9057	X 9100	9071	959·4°	958·0°	1
26	-0·3	-3	A 9087	9083	Y 9159	9141	959·9	958·6	2
27	-0·8	-9	A 9066	9083	Y 9119	9141	959·9	960·4	2
35	-0·7	-8	A 9079	9082	Y 9142	9141	959·7	959·4	1
36	-0·1	-1	A 9097	9082	Y 9163	9141	959·4	958·7	1
41	-0·3	-3	A 9083	9081	Y 9156	9141	959·6	958·5	2
42	-0·8	-9	A 9076	9081	Y 9131	9141	959·3	959·7	2
63	-0·6	-7	A 9079	9084	Z 9010	9019	960·7	961·1	2
			D 9048	9058			961·2		
							960·9		



TABLE VIII—(Continued)

Exp. No.	Integrated correction to outside elements Degr's M.V.		Standard Elements				Temperature		Weight
			Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	By Outside Element	By Inside Element	
Silver Point—(Cont.)									
68	-0.7	-8	A 9080 D 9051	9085 9058	Z 9018	9019	960.3° 960.4 960.4	960.3°	2
76	-0.2	-2	A 9088 E 9112 F 9097 G 9106	9082 9113 9113 9111	Z 9002	9018	959.2 959.7 961.2 960.2 960.1	961.2	4
81	+0.3	+3	F 9132 E 9131 A 9083 G 9125	9113 9113 9082 9111	Z 9015	9018	959.5 959.6 961.1 960.0 960.0	961.5	4
88	+0.3	+3	F 9143 E 9139 A 9093 G 9135	9113 9113 9082 9112	Z 9026	9018	959.0 959.4 960.7 959.6 959.7	960.1	4
Weighted Mean,							959.9°	960.2°	
Gold Point. 1062.4°									
64	-0.3	-3	A 10262 D 10226	10265 10233	Z 10178	10193	1062.4° 1062.8 1062.6	1063.4°	2
69	-0.4	-4	A 10253 D 10217	10266 10234	Z 10169	10193	1061.4 1061.7 1061.6	1062.3	2
77	-0.3	-3	A 10255 E 10282 F 10263 G 10276	10263 10295 10296 10294	Z 10161	10193	1061.2 1061.6 1063.4 1062.1 1062.1	1063.3	4
82	+0.4	+4	F 10303 E 10304 A 10256 G 10296	10296 10295 10263 10294	Z 10181	10193	1061.9 1061.8 1063.1 1062.4 1062.3	1063.6	4
Weighted Mean,							1062.2°	1063.2°	
Copper Point. 1082.6° (Lower Pressure. p <sub>0</sub> =217-221mm)									
2	+1.2	+14	W 10457	10478	X 10491	-----	1081.7	-----	1
9	+1.0	+12	W 10495	10478	X 10555	-----	1082.2	-----	1
11	+1.2	+14	W 10487	10478	X 10512	-----	1083.1	-----	1
18	+0.7	+8	A 10510	10502	Y 10612	10573	1082.2	-----	2
19	-0.4	-5	A 10501	10502	Y 10584	10573	1082.0	1081.0	3

TABLE VIII—(Continued)

Exp. No.	Integrated correction to outside elements		Standard Elements				Temperature		Weight								
	Degr's	M. V.	Outside Corrected	Fixed Pt.	Inside Uncor- rected	Fixed Pt.	By Outside Element	By Inside Element									
Copper Point (Lower Pressure)—Cont.																	
20	-0.8	- 9	A 10488	10502	Y 10555	10573	1082.1°	1082.5°	3								
28	-0.3	- 4	A 10512	10501	Y 10593	10573	1082.1	1081.4	3								
29	-0.9	-10	A 10494	10501	Y 10558	10573	1082.2	1083.0	3								
37	-0.6	- 7	A 10504	10501	Y 10576	10573	1082.0	1082.0	2								
38	-0.3	- 4	A 10509	10500	Y 10585	10573	1082.2	1081.9	2								
39	+0.7	+ 8	A 10517	10500	Y 10617	---	1082.3	---	2								
43	-0.3	- 4	A 10512	10500	Y 10595	10573	1082.2	1081.3	3								
44	-0.9	-10	A 10501	10499	Y 10568	10573	1082.0	1082.6	3								
45	+0.6	+ 7	A 10515	10499	Y 10617	----	1082.3	----	2								
89	+0.5	+ 6	F 10546	10534			1081.8										
			E 10544	10534			1081.9										
			A 10496	10503			1083.4										
			G 10538	10533			1082.4										
126*	+0.4	+ 5					1082.4	1083.1	4								
							E 10631			10534	1082.2						
							F 10627			10534	1082.6						
							G 10621			10533	1083.0						
									1083.0								
									H 10623			10535	C 10567	10470	1082.7		
																	1082.5
																	4
			Weighted Mean							1082.2°	1082.2°						
			Copper Point—Cont. (Higher Pressure. $p_0=346-347^{\text{mm}}$ )														
60	-0.7	- 8	A 10500	10502	Z 10422	10432	1083.4°	1084.1°	1								
			D 10465	10470			1083.6										
							1083.5										
65	-0.8	- 9	A 10502	10503	Z 10420	10432	1083.0	1083.9	2								
			D 10465	10471			1083.4										
							1083.2										
70	-0.3	- 4	A 10508	10504	Z 10444	10432	1082.4	1081.8	2								
			D 10475	10472			1082.6										
							1082.5										
78	-0.1	- 1	A 10502	10503	Z 10404	10432	1081.4	1083.7	4								
			E 10523	10534			1081.8										
			F 10509	10534			1083.4										
			G 10522	10533			1082.3										
							1082.2										
83	+0.1	+ 1	F 10535	10534			1082.1										
			E 10535	10534			1082.1										
			A 10488	10503			1083.5										
			G 10527	10533			1082.7										
							1082.6	1084.6	4								

\* Made with outside-wound furnace. See page 106.

TABLE VIII—(Continued)

Exp. No.	Integrated correction to outside elements		Standard Elements				Temperature		Weight
			Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	By Outside Element	By Inside Element	
	Deg's	M. V.							
<i>Copper Point—Cont. (Higher Pressure)</i>									
84	+0.7	+ 8	F 10544	10534			1082.0°		4
			E 10542	10584			1082.3		
			A 10493	10503			1083.8		
			G 10533	10533	Z 10426	10432	1083.0		
							1082.8	1083.5	
			Weighted Mean,				1082.7°	1083.7°	
			Mean of 2 pressures,				1082.5°	1082.9°	

*Diopside Point. 1391.2°*

96	0.0	0	E 14227	14228			1392.1°		1
			F 14222	14229			1392.5		
			G 14245	14229			1390.7		
			H 14251	14231	Z 14121	14108	1390.4		
							1391.4	1390.5°	
97	+1.0	+13	E 14260	14228			1392.4		1
			F 14254	14229			1393.0		
			G 14287	14229			1390.4		
			H 14295	14231	Z 14156	14103	1389.9		
							1391.4	1390.5	
99	-0.1	- 1	E 14218	14228			1394.5		1
			F 14195	14229			1396.0		
			G 14215	14229			1394.4		
			H 14212	14231	Z 14099	14108	1394.8		
							1394.9	1393.7	
100	+0.7	+ 9	E 14251	14228			1394.4		1
			F 14244	14229			1395.0		
			G 14268	14229			1393.1		
			H 14273	14231	Z 14156	14108	1392.9		
							1393.8	1391.8	
103	-0.4	- 5	E 14211	14228			1392.5		3
			F 14204	14229			1393.1		
			G 14217	14229			1392.1		
			H 14230	14231	Z 14124	14103	1391.2		
							1392.2	1389.4	
104	+1.0	+13	E 14242	14228			1392.5		3
			F 14212	14229			1394.9		
			G 14249	14229			1392.0		
			H 14262	14231	Z 14155	14103	1391.1		
							1392.6	1389.3	

TABLE VIII—(Continued)

Exp. No.	Integrated correction to outside elements Degr's M. V.		Standard Elements				Temperature		Weight
			Outside Corrected	Fixed Pt.	Inside Uncor- rected	Fixed Pt.	By Outside Element	By Inside Element	
Diopside Point—(Cont.)									
106	-0.6	- 8	E 14228	14228			1391.7°		2
			F 14225	14229			1392.0		
			G 14233	14229			1391.8		
			H 14243	14231	Z 14123	14103	1390.7	1390.0°	
						1391.4			
107	+0.9	+ 12	E 14248	14228			1391.9		2
			F 14237	14229			1392.8		
			G 14245	14229			1392.2		
			H 14252	14231	Z 14152	14103	1391.8	1389.4	
						1392.2			
130	-0.6	- 7	E 14243	14228			1390.2		3
			F 14241	14230			1390.6		
			G 14249	14230			1389.9		
			H 14239	14228	C 14146	14153	1390.6		
						1390.8	1392.0		
Weighted Mean,							1392.0°	1390.4°	
Nickel Point. 1452.8°									
109	+0.7	+ 8	E 15028	14977			1451.2°		1
			H 15027	14980	Z 14903	14850	1451.6		
							1451.4	1451.1°	
111	0	0	E 14980	14977			1453.2		2
			H 14978	14980	Z 14867	14850	1453.7		
							1453.5	1452.1	
112	+0.9	+ 11	E 14971	14977			1453.8		2
			F 14958	14978			1454.9		
			H 14991	14980	Z 14872	14850	1452.4		
							1453.7	1451.5	
123	-0.6	- 7	E 14984	14977			1454.3		2
			F 14989	14978	A 14982	14945	1453.9		
							1454.1	1451.8	
124	+0.8	+ 10	E 14989	14977			1454.6		1
			F 14994	14978	A 14996	14945	1454.3		
							1454.5	1451.5	
133	-0.3	- 4	E 14954	14977			1451.9		4
			F 14958	14976			1451.5		
			G 14955	14981			1452.2		
			H 14946	14977	C 14882	14898	1452.5		
						1452.0°	1451.3°		
Weighted Mean,							1453.0°	1451.6°	

TABLE VIII—(Continued)

Exp. No.	Integrated correction to outside elements		Standard Elements				Temperature		Weight
	Degr's	M. V.	Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	By Inside Element	By Outside Element	
Cobalt Point. 1489·8°									
115	+0·1	+ 1	E 15390	15439	A 15357	15409	1488·7°	1488·9°	3
			F 15375	15435			1489·6		
							1489·1		
116	+1·4	+17	E 15428	15439	A 15421	15409	1490·5	1488·6	3
			F 15434	15435			1489·7		
			G 15435	15441			1490·1		
118	-0·5	- 6	E 15385	15439	A 15382	15409	1491·7	1489·6	2
			F 15383	15435			1491·6		
			G 15393	15441			1491·8		
120	-0·4	- 5	E 15381	15439	A 15379	15409	1491·7	1489·4	1
			F 15371	15435			1492·1		
			G 15363	15441			1493·8		
121	+0·7	+ 9	E 15406	15439	A 15412	15409	1492·0	1489·1	1
			F 15405	15435			1491·8		
			G 15398	15441			1492·8		
						1492·2			
						1490·6°	1489·0°		
Palladium Point. 1549·2°									
134	-0·7	- 9	E 16151	16143	C 16075	16058	1549·5°	1548·8°	
			F 16161	16138			1548·3		
			G 16139	16145			1550·6		
			H 16147	16145			1550·1		
						1549·6°			
Anorthite Point. 1549·5°									
134	-0·7	- 9	E 16151	16148	C 16075	16060	1549·9°	1549·0°	
			F 16161	16141			1548·6		
			G 16139	16148			1550·9		
			H 16147	16145			1550·0		
						1549·9°			
Interpolation Points.									
49	-0·1	- 1	A 2486	2492	Z 2462	2465	320·2°	319·9°	
			D 2482	2486			320·0		
							320·1		
							320·0°		
Mean for cadmium,									
51	0·0	0	A 4451	4450	Z 4413	4417	524·6	525·1	
			D 4439	4442			525·0		
							524·8		
							524·9°		
Mean for A = 4450,									

TABLE VIII—(Concluded)

Exp. No.	Integrated correction to outside elements Degrs M. V.		Standard Elements				Temperature		Weight
			Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	By Inside Element	By Outside Element	
Interpolation Points—(Cont.).									
62	0.0	0	A 7895	7900	Z 7829	7848	854.2°	855.5°	
			D 7869	7881			854.9		
							854.6		
67	-0.2	-2	A 7883	7900	Z 7820	7848	854.0	855.0	
			D 7859	7881			854.5		
							854.3		
			Mean for A = 7900,				854.7°		
128	-0.2	-2	E 12004	12000	C 11914	11928	1206.3	1207.8	
			F 12001	12001			1206.7		
			G 12008	12001			1206.1		
			H 12000	12003			1206.9		
							1206.5		
132	+0.1	+1	E 11947	12000	C 11887	11928	1206.0	1205.0	
			F 11952	11097			1205.3		
			G 11950	12001			1205.8		
			H 11941	12008			1206.8		
							1206.0		
			Mean for E = 12000,				1206.4°		
129	-0.6	-5	E 13107	13100	C 13007	13028	1297.4	1299.3	
			F 13102	13101			1297.9		
			G 13110	13101			1297.2		
			H 13101	13108			1298.1		
							1297.7		
			Mean for E = 13100,				1298.5°		

(Continued from p. 140.)

If the investigator's responsibility could be made to end with the representation of his own observations, no serious difficulty would arise, but such a formula when published is placed in the hands of many who do not realize that no physical significance was attached to the formula by its author and that its extrapolation in either direction would be fraught with grave danger. A mere inspection of the equation is sufficient to show that the electromotive force does not become zero for zero temperature, thereby immediately proving that extrapolation downward does not correspond to the observed readings of the thermoelement. In the Reichsanstalt equation this constant term was in fact sufficiently large to lead to absurdities if the extrapolation was continued far below 300°.

Notwithstanding the warning contained in this situation, extrapolation upward of the thermoelectric curve has been

employed almost universally for the determination of temperatures above  $1100^{\circ}$ , not only for direct determinations of temperature with the thermoelement itself, but also for the calibration of optical pyrometric apparatus. The absence of absolute determinations in this region has left this practice in undisturbed security until recently, when some doubt has been thrown upon the validity of irresponsible upward extrapolation by various observations. (1) The increase in the accuracy now attainable with the optical pyrometer has given an independent thermal scale comparable with that of the thermoelement and overlapping the same region. The two curves have not been found to correspond. (2) Experimental determinations of the melting point of platinum by continuing observations of the thermoelement up to a point where a portion of its platinum wire melts, have been undertaken in the national laboratories of Germany, England and the United States, and have yielded a value measured upon the extrapolated thermoelectric curve of about  $1710^{\circ}$ . The agreement in the different determinations was good and the result found general acceptance for a time. More recently, Holborn and Valentiner have made successful measurements with the gas thermometer at the temperature of melting palladium, and although high accuracy was not attempted, it became clear that the palladium point obtained by extrapolating with the thermoelement was much too low and by inference the platinum point also, for the various optical methods give opportunity for a very good determination of the temperature difference between the melting points of the two metals. The most recent estimates of the platinum melting point obtained in this way place it between  $1750^{\circ}$  and  $1775^{\circ}$ , indicating that the upward extrapolation with the thermoelement has given rise to an error of about  $50^{\circ}$  at the platinum point.

The data obtained in the present investigation throw much light upon this situation. If we take the observations of our series over the range covered by the Reichsanstalt scale ( $300^{\circ}$  to  $1100^{\circ}$ ) and write an equation for these of the same type as that used at the Reichsanstalt, it will read,

$$E = -302 + 8.2356t + .0016393t^2$$

and this equation will reproduce the temperatures of the standard melting points which fall in this region with a maximum error of 3 microvolts, an accuracy far within the errors of observation. But if we extrapolate this curve in accordance with the general practice above described, and compare the resulting electromotive forces with our observations between  $1100^{\circ}$  and

1550°, a somewhat startling surprise awaits us. Although the curve below the copper point is a practically perfect reproduction of the observations, it diverges from the gas thermometer scale at the melting point of palladium by 245 microvolts, which represents a temperature error of nearly 20°. This comparison is made in the table below :

	Temperature	Observed Microvolts	Calculated Microvolts	Observed— Calculated Microvolts
Zinc .....	418·2°	3429	3429	0
Antimony ...	629·2	5530	5530	0
Silver .....	960·0	9113	9115	—2
Gold .....	1062·4	10295	10298	—3
Copper .....	1082·6	10534	10534	0

*Extrapolation.*

	1207·1	12000	12027	—27
	1298·8	13100	13161	—61
Diopside ....	1391·2	14228	14338	—110
Nickel .....	1452·3	14945	15112	—167
Cobalt .....	1489·8	15439	15608	—169
Palladium ...	1549·2	16143	16388	—245

If, on the other hand, we follow Day and Clement, and represent  $t$  as a function of  $E$ , using the same data as before, the equation will take the form

$$t = 47·2 + ·11297E - 1·3946(10)^{-6}E^2$$

This curve passes through the fixed points below 1100° nearly as accurately as the previous one, and is also quite competent to interpolate temperatures throughout the range of the old standard scale. Extrapolating this in turn up to the palladium point and comparing it with our gas thermometer measurements in the higher region leads to temperatures about 40° too low.

	Observed	Calculated	Observed— Calculated
Zinc .....	418·2°	418·2°	0°
Antimony ...	629·2	629·3	—0·1
Silver .....	960·0	960·9	—0·9
Gold .....	1062·4	1062·4	0
Copper .....	1082·6	1082·5	+0·1

*Extrapolation*

	1207·1	1202·0	+5·1
	1298·8	1287·8	+11·0
Diopside ....	1391·2	1372·0	+19·2
Nickel .....	1452·3	1424·0	+28·3
Cobalt .....	1489·8	1459·0	+30·8
Palladium ...	1549·2	1507·0	+42·2



The untrustworthiness of the present practice of extending thermoelement values obtained below 1100° into the region above that temperature is therefore abundantly demonstrated.\*

We were unable to find a simple parabola with which to represent the whole series of observations between 300° and 1550° within the errors of observation. The simplest procedure is therefore to divide the long curve into two parts. This plan is carried out below in the form in which it will probably be found most useful. A parabola passing through zinc, antimony and copper reproduces the results over that temperature range within the errors of observation. A similar parabola through copper, diopside and palladium gives the upper temperatures as accurately as they were measured. These two equations offer a means of safe and convenient interpolation throughout the entire range of the gas thermometer measurements. In this series are included certain gas thermometer measurements given at the end of Table VIII which were made at temperatures between the fixed melting points, for the purpose of checking the interpolation formula, together with a single gas thermometer determination of the cadmium melting point. The temperature 854.1 appears here corrected by  $-0.6^\circ$ , since the series, of which this measurement formed a part, showed a systematic difference of about this amount from the final average of antimony and silver, which lie on either side of this point.

*Cadmium to Copper*

$$E = -302 + 8.2356t + .0016393t^2$$

	Temperature	Observed Microvolts	Calculated Microvolts	Observed— Calculated Microvolts
Cadmium .....	320.0°	2504	2501	+3
Zinc .....	418.2	3429	3429	0
	524.9	4470	4472	-2
Antimony .....	629.2	5530	5530	0
	854.1	7927	7928	-1
Silver .....	960.0	9113	9115	-2
Gold .....	1062.4	10295	10298	-3
Copper .....	1082.6	10534	10534	0

*Copper to Palladium*

$$E = -1941 + 11.1746t + .00032161t^2$$

Copper .....	1082.6	10534	10534	0
	1207.1	12000	12010	-10
	1298.8	13100	13112	-12
Diopside .....	1391.2	14228	14228	0
Nickel .....	1452.3	14977	14967	+10
Cobalt .....	1489.8	15439	15421	+18
Palladium .....	1549.2	16143	16143	0

\* For an account of some of the dangers of careless interpolation, see Day and Clement, loc. cit., p. 453.

It is possible to write a cubic equation which will reproduce the entire series from zinc to palladium without error greater than the normal accuracy of the observations themselves. The equation offered makes no pretensions to a least square solution with balanced residuals, but is arranged so that the greatest uncertainties are found in that portion of the curve where the greatest experimental error lies. The coefficients were rounded off for convenience of computation.

*Cadmium to Palladium*

$$E = -169 \cdot + 7 \cdot 57t + 0 \cdot 002648t^2 - 0 \cdot 0000004724t^3$$

	Temperature	Observed Microvolts	Calculated Microvolts	Observed— Calculated Microvolts
Cadmium .....	320·0°	2504	2509	—5
Zinc .....	418·2	3429	3425	+4
	524·9	4470	4466	+4
Antimony .....	629·2	5530	5525	+5
	854·1	7929	7934	—5
Silver .....	960·0	9113	9121	—8
Gold .....	1062·4	10295	10296	—1
Copper .....	1082·6	10534	10530	+4
	1206·4	12000	11988	+12
	1298·5	13100	13091	+9
Diopside .....	1391·2	14228	14215	+13
Nickel .....	1452·3	14977	14963	+14
Cobalt .....	1489·8	15439	15424	+15
Palladium .....	1549·2	16143	16157	—14

6. *Analysis of Metals.* (By E. T. Allen.)

The object of these analyses was primarily, of course, to decide whether the metals should be used or rejected for the temperature scale, and those selected were examined very carefully so that in the future, when more is known about the specific lowering which the various impurities produce on the melting point, corrections may be made if desirable.

The accuracy of the determinations is problematical. There is of course the possibility of increased solubility of difficultly soluble compounds in the comparatively concentrated solutions of the metals from which the impurities have to be precipitated, viz., 5 to 6 g. in 250<sup>cc</sup> volume. Also, when it is necessary to separate the bulk of the metal by precipitation from the impurities, as it sometimes is, one cannot be sure that the impurity sought is not occluded by the precipitates. In most cases, the latter source of error is probably the more serious. Only methods worked out synthetically with materials laboriously prepared could decide these questions. Large quantities of metal, 25 to 100 g., were generally taken for analysis, and

since the impurities were weighed to the tenth of a milligram, the results are generally stated to the ten-thousandth of a per cent. This does not mean that the results are considered accurate to this figure. The variation in successive determinations comes in the thousandths, so that the fourth decimal place may have about as much value as the second in an ordinary analysis. Great pains have been taken to purify precipitates, often by many precipitations, so that in all cases the figures given may be regarded as minima. In all cases, too, I have endeavored to avoid missing anything, by repeating every process, rejecting no precipitate or solution until it was decided that nothing more was to be gotten from it. In any reasonable case of suspicion, blank determinations were made with the reagents.\*

#### *Heraeus' Palladium.*

The palladium was naturally suspected to contain other metals of the platinum group. It is well known that the separation of these metals is a problem of unusual difficulty. The plan here was therefore to precipitate most of the palladium from solution as one of its characteristic compounds and, while the filtrate was reserved for impurities, to redissolve and again precipitate the metal as another characteristic compound. In this way it was hoped that those impurities which were retained by the first precipitate would not be occluded by the second. The sheet metal was first cut into shavings on a milling machine which was especially cleaned for the purpose. Then the shavings were boiled a short time with dilute hydrochloric acid to remove any iron from the surface, washed and dried. After an unsuccessful endeavor to dissolve the palladium in nitric acid (insoluble brown hydroxide (?) always formed), it was dissolved in aqua regia and rid of nitric acid by successive evaporations with excess of hydrochloric acid. It was then dissolved in dilute hydrochloric acid and diluted further to about 1 l. Ammonia was added in excess.† A precipitate came down and redissolved on warming—all but a little ferric hydroxide which was filtered off. The filtrate was then evaporated again to about 250<sup>cc</sup>, diluted and precipitated with stirring, by dilute hydrochloric acid. The voluminous precipitate of  $\text{PdCl}_2 \cdot 2\text{NH}_3$  was now filtered and washed on a Büchner porcelain funnel, using suction. The filtrate we will call "solution A." The precipitate was then dried and

\* After considerable experience in the examination of these "pure" metals, the writer has reached the conclusion that a 10 g. portion, in the great majority of cases, will give as satisfactory results as a larger portion and with far less labor.

† E. F. Smith and H. F. Keller, Amer. Chem. Jour., xiv, 423, 1892.

ignited in a large porcelain crucible. The resulting metal was dissolved in aqua regia and freed of nitric acid. This solution was diluted and precipitated by potassium iodide, and the filtrate—"solution B"—removed as above.

From solutions A and B, separately, the platinum metals were first removed by long boiling with ammonium formate. The metal—1 to 2 g. in weight, mostly palladium—was filtered and the filtrate and washings were examined further for other heavy metals by the usual methods.

*Separation of the Palladium from the Platinum Metals.*—Considering now the ammonium formate precipitate, Erdmann and Makowka\* have obtained satisfactory separations of palladium from platinum and iridium by treating the solution of the mixed chlorides with acetylene. Palladium comes down as acetylide and the other metals are unprecipitated. I found also that *rhodium* solutions even on heating were not precipitated by acetylene. As for osmium, the ease with which it oxidizes and the high volatility of its oxide makes its elimination, in the process of preparing the palladium, fairly certain. Ruthenium, the rarest element among the platinum metals, need hardly be looked for; still it was sought for in the iridium found. The acetylene method was used, for lack of a safer one, though very tedious. In solutions at all concentrated, I find the palladium ceases to precipitate long before it is entirely removed from solution. Perhaps this is due to the accumulation of acid liberated in the process. At least, when the solution is separated from the acetylide, evaporated and diluted again, acetylene brings down another portion. After five or six operations, a residual solution was obtained on which acetylene had no further action. The acetylide was now carefully ignited with a little ammonium nitrate, the metal redissolved, and the whole process repeated. The residual solution was then added to the first and from it  $\text{NH}_4\text{Cl}$  brought down platinum. In the chlor-platinate no iridium was found. It was ignited and the metal was entirely soluble in a few drops of aqua regia. It was again precipitated with  $\text{NH}_4\text{Cl}$  and finally weighed as platinum— $\text{Pt} = 1.6 \text{ mg.} = 0.007 \text{ per cent.}$  No rhodium was found in the filtrate. In the attempt to dissolve in aqua regia the several portions of metal formed by igniting the acetylide, tiny insoluble residues accumulated. These were fused with  $\text{KHSO}_4$ , which, as is well known, dissolves palladium and rhodium but not iridium or platinum if the temperature is kept low. The soluble portion was dissolved in water and precipitated with ammonium formate. It turned out to be palladium, since it was precipitated by potassium iodide and no trace of rhodium was found.

\* Zeitschr. anal. Chemie, xlvi, 146, 147, 1907.

The portion insoluble in  $\text{KHSO}_4$  was freed from silica (which came from the dish) by  $\text{HCl} + \text{HF}$ , ignited, and weighed.  $\text{Ir} + [\text{Ru}] = 1.9 \text{ mg.} = 0.008 \text{ per cent.}$  When fused with  $\text{K}_2\text{CO}_3 + \text{KNO}_3$ , some blue insoluble  $\text{IrO}_3$  was formed, but the fusion showed no yellow color, and in view of the minute quantity of material, it was not thought worth while to search more carefully for ruthenium.

The final precipitate of palladium acetylide was changed to chloride, diluted, and saturated with  $\text{SO}_2$  for gold, but none appeared.

Nothing else was found in the metal except a trace of copper. The iron found earlier had to be reprecipitated several times from chloride solution by ammonia to get rid of palladium. The precipitate was finally transformed into sulphate and determined volumetrically.— $\text{Fe} = 2.6 \text{ mg.} = 0.10 \text{ per cent.}$

#### *Analysis of Palladium.*

Au .....	none
Ru .....	none
Rh .....	none
Pt .....	0.07%
Ir .....	0.08%
Cu .....	trace
Zn .....	doubtful trace
Fe .....	0.10%
	<hr/>
	0.25%

#### *Kahlbaum's Electrolytic Nickel.*

Two 50 gram portions were dissolved separately in measured quantities of nitric acid and then carried to white fumes with excess of sulphuric acid. Both portions were then dissolved in water and filtered. There was a small dark residue which was washed thoroughly and extracted with aqua regia, leaving a little silica from the dish. The yellow chloride obtained was freed from nitric acid, saturated with  $\text{SO}_2$ , and left to stand. *No gold.* Changed to chloride again and tested with caustic soda and  $\text{H}_2\text{O}_2$ . *Still no gold.* Acidified and reprecipitated with  $\text{NH}_4\text{Cl}$ , a characteristic yellow precipitate was obtained. Confirmed by dissolving the chlor-platinate in hot water and precipitating by hydrogen.  $\text{Pt} = 2.3 \text{ mg.} = 0.0023 \text{ per cent.}$  The main solution was then precipitated by  $\text{H}_2\text{S}$  ( $v = 2 \text{ l.}$ ). The small black precipitate obtained was worked over for gold and platinum with the above.

Other heavy metals were tested for in the ordinary way.  $0.2 \text{ mg. PbSO}_4 = \text{about } 0.1 \text{ mg. Pb.}$   $\text{Cu} = 52.3 \text{ mg.} = 0.0523 \text{ per cent.}$

*Ammonium Sulphide Group.*—The voluminous solution was now freed from hydrogen sulphide by evaporation, some

ammonium persulphate was added and a stream of air passed through the solution for some time. *No manganese.*  $\text{Fe}_2\text{O}_3 = 6.1$  mg., after repeated precipitation.  $\text{Fe} = 4.2$  mg. Repeated efforts were made to separate zinc with  $\text{H}_2\text{S}$  on the principle of the lower solubility of  $\text{ZnS}$  in dilute acids, but without satisfaction. First I tried to precipitate a small fraction of the nickel, hoping to get all the zinc with it. The volume of the solution was about 5 l. But unless so much acid was added that strong doubts were entertained of recovering any zinc that might be present, the fraction of the nickel precipitate was far too great. Again, all the nickel was precipitated and the precipitate was digested with cold 10 per cent solution of hydrochloric acid. Here one had to fear either the failure to remove the zinc or the removal of too much nickel to handle without so many precipitations that a small quantity of zinc would probably be lost. It is doubtful whether we have any method which will give very small amounts of zinc in metallic nickel.

The whole solution was now tested for cobalt as follows: It was freed from  $\text{H}_2\text{S}$  by evaporation, acidulated with  $\text{HCl}$  and precipitated by  $\alpha$ -nitroso- $\beta$ -naphthol in 50 per cent acetic acid. This was added in several portions. After long standing the precipitate was collected and washed. The voluminous precipitate was very cautiously burned in a capacious porcelain crucible. Much tar was formed. The residual oxide was dissolved in nitric acid and the cobalt separated from nickel by  $\text{KNO}_3$  in the usual way. The potassium cobalto-nitrite was finally decomposed by sulphuric acid and precipitated electrolytically from ammoniacal solution.  $\text{Co} = 101.4$  mg.  $+ 4.9$  mg. recovered from filtrate and weighed as sulphate. Total =  $0.1063$  per cent.  $\text{Fe}$  and  $\text{Co}$  were also determined in a separate 10 g. portion of metal.  $\text{Fe}_2\text{O}_3 = 0.7$  mg.  $\text{Fe} = 0.49$  mg. =  $0.0049$  per cent.  $\text{Co} = 10.3$  mg. =  $0.1030$  per cent. A separate 10 g. portion was taken for sulphur. It was dissolved in nitric and evaporated on the water bath. This solution was diluted and precipitated with a slight excess of sodium carbonate. The filtrate was just acidulated, evaporated, and treated with barium chloride. No precipitate.

#### Analysis of Nickel.

Au.....	none	Bi.....	none
Pt.....	$\cdot 0023\%$	Cd.....	"
As.....	none	Zn.....	none found
Sb.....	"	Co.....	$\cdot 1063\%$
Sn.....	"	Mn.....	none
Pb.....	$\cdot 0001\%$	Fe.....	$\cdot 0042\%$
Cu.....	$\cdot 0523\%$	S.....	none
			<hr/>
			$\cdot 165\%$

*Kahlbaum's Cobalt.*

Two 25 g. portions of the metal in the form of powder were dissolved in 150<sup>cc</sup> water + 35<sup>cc</sup> concentrated  $\text{H}_2\text{SO}_4$ . The analysis was quite similar to that of the nickel. In the  $\text{H}_2\text{S}$  group were found:  $\text{Cu} = 8.9 \text{ mg.} = 0.0178 \text{ per cent.}$   $\text{PbSO}_4 = 12.9 \text{ mg.}$   $\text{Pb} = 0.176 \text{ per cent.}$  In the  $(\text{NH}_4)_2\text{S}$  group manganese was tested for as in the nickel. None was found.  $\text{Fe}_2\text{O}_3 = 0.9 \text{ mg.}$   $\text{Fe} = 0.0006 \text{ per cent.}$  As the tests for Ni and Zn were unsatisfactory, another portion of 25 g. was dissolved in dilute sulphuric acid and precipitated by  $\text{H}_2\text{S}$ . The filtrate from the sulphides was filtered and freed from excess of  $\text{H}_2\text{S}$  by evaporation. Then it was diluted to 1 liter and divided into two portions. Both were neutralized by sodium carbonate. In the one, manganese was sought for by ammonium persulphate. In the other nickel was looked for. A little ammonia was added and then an alcoholic solution of dimethylglyoxime. A precipitate containing much cobalt was obtained. This was worked over for nickel but none was found. For sulphur the method used in the analysis of nickel was followed.  $\text{BaSO}_4 = 14.4 \text{ mg.}$ , blank = 5.1 mg., difference = 9.3 mg.,  $\text{S} = 0.013 \text{ per cent.}$

*Analysis of Cobalt.*

Ag.....	none	Cu .....	0.0178%
Au.....	"	Bi .....	none
Pt .....	"	Cd .....	"
As .....	"	Zn .....	"
Sb .....	"	Ni .....	"
Sn .....	"	Fe .....	0.0006%
Pb.....	0.176%	Mn.....	none
		S .....	0.013%
			<hr/> 0.049%

*Aluminum.*

Owing to the difficulty of handling this metal, small portions (10 g.) only were taken for analysis. *Heavy metals*, except arsenic and antimony, were sought for in the hydrochloric acid solution by ordinary methods. Only a trace of copper was found.

*Phosphorus, Arsenic, and Sulphur.*—For these elements, a separate portion was dissolved in caustic alkali in a special apparatus entirely of glass. The vessel was first filled with purified hydrogen and then the alkali was introduced and the gases evolved were passed through silver nitrate solution. At the end, the gases remaining in the vessel were displaced by hydrogen. The precipitated silver was worked over for the different elements. *No As nor Sb.* A separate portion was used for sulphur.  $\text{BaSO}_4 = 1.4 \text{ mg.}$   $\text{S} = 0.002 \text{ per cent.}$

*Silicon.*—10 g. metal were dissolved in a mixture of nitric and sulphuric acids, using a platinum dish. With hydrochloric acid alone nearly all the silicon is lost as hydride. The brown amorphous residue was filtered, washed and fused with sodium carbonate. From the fusion silica was obtained in the usual way.  $\text{SiO}_2 = 41.4$  mg.  $\text{Si} = 0.194$  per cent. Repetitions gave 0.189 per cent and 0.190 per cent.

*Carbon.*—10 g. metal were dissolved in NaOH and filtered through glowd asbestos, washed first with water, then with dilute acid and finally with water and dried at  $105^\circ$ . The asbestos and residue were then transferred to a combustion tube and burned in air free from  $\text{CO}_2$ . The gases were passed through standard  $\text{Ba}(\text{OH})_2$ . A considerable precipitate was obtained, while a blank gave no trace. The excess of  $\text{Ba}(\text{OH})_2$  was the ntitrated with standard acid using phenolphthalein as indicator. 5.05 mg.  $\text{CO}_2$  found.  $\text{C} = 0.014$  per cent. A duplicate in which the metal was dissolved in KOH gave 0.012 per cent.

*Iron.*—10 g. metal were dissolved in hydrochloric acid, and to the solution was added tartaric acid free from iron. From this solution the iron was precipitated by colorless ammonium sulphide. The precipitate was finally changed to sulphate and determined volumetrically.  $\text{Fe} = 4.6$  mg. Blank determination gave 0.3 mg.  $\text{Fe} = 0.043$  per cent.

*Calcium, Sodium, and Potassium* were sought for in the hydrochloric acid solution, by precipitating with ammonia, washing the large precipitate and testing the evaporated filtrate. *No Ca.* Some alkaline chloride was found, but a blank showed that it came from the ammonia, as there was only a difference of 1.6 mg. between the chloride of the blank and that in the determination. *No Na or K.*

#### Analysis of Aluminum.

As .....	none	C .....	0.013%
Sb .....	"	S .....	0.002%
P .....	"	Ca .....	none
Cu .....	0.003%	Na .....	"
Fe .....	0.043%	K .....	"
Si .....	0.190%		
			0.251%

#### Antimony.

g. metal were powdered in an agate mortar and treated with 35 per cent  $\text{HNO}_3$  on the steam bath. As soon as the reaction was practically complete, the antimonie acid was extracted



with hot dilute nitric acid, transferred to a filter and washed with water. The filtrate and washings were then evaporated to dryness with hydrochloric acid, while the antimonie acid was digested repeatedly with yellow sodium sulphide till the soluble portion was dissolved. The residue, after a little washing, was dissolved in nitric acid, evaporated to dryness, freed from nitric by hydrochloric acid, and the chlorides united with the first extract. The whole was precipitated by hydrogen sulphide. The washed sulphides were then extracted with colorless ammonium sulphide. From this solution the sulphides were thrown down by acid, filtered and washed. Then they were dissolved in hot dilute caustic potash. The solution was boiled with perhydrol for complete oxidation, and arsenic sought for by Fischer's method, viz., reducing by ferrous ammonium sulphate and distilling in a current of hydrochloric acid gas. *No As.*

A separate portion of 5 g. was taken for tin. McCay's method was tried.\*  $\text{SnO}_2 = 1.3 \text{ mg.}$   $\text{Sn} = 1.0 \text{ mg.} = .02 \text{ per cent.}$

A separate portion of 25 g. was used for sulphur. The metal was oxidized by nitric acid as before, and the soluble portion separated and evaporated. The residue was then heated with a small excess of sodium carbonate and filtered. The residue was also boiled out several times with sodium carbonate solution. The two solutions were then acidified with hydrochloric acid and treated with barium chloride. The portion soluble in nitric acid gave a slight precipitate, which was further purified, after the usual washing and drying, by fusion with sodium carbonate. The water extract containing the soluble sulphate was acidified and precipitated a second time.  $\text{BaSO}_4 = \text{trace.}$

#### *Analysis of Antimony.*

As.....	none	Cd .....	none
Sn.....	0.02 (?)	Ni .....	"
Ag.....	none	Co .....	"
Pb.....	trace (?)	Mn .....	"
Cu.....	0.004	Zn .....	"
Bi.....	none	Fe.....	0.007%
		S .....	trace (?)
			<hr/>
			.031%

In the following table, the results of these and previous† analyses of metals for the temperature scale are summarized:

\* Private communication.

† Day and Clement, loc. cit., p. 454.

Summarized Analyses of Metals.\*

Impurities stated in fractions of 1%	Metals							
	Palla- dium	Cobalt	Nickel	Copper	Silver	Alum- inum	Antimony	Zinc
Pt	0·007	none	·0023	·0011†	·0001			
Ir	·008							
Rh	none							
Ru	"							
Au		none	none	none	·0005			
Se				"				
Te				"				
As		none	none	"	none	none	none	none
Sb		"	"	"	"	"		·002
Sn		"	"	"	"		·02 (?)	
Hg					"		none	
Ag		none	none	·0006			"	none
Pb	none	·0176	·0001	none	·0008			·051
Bi	"	none	none	"	none		none	none
Cu	trace	·0178	·0523		trace	·003	·004	none
Cd	none	none	none	none	none		none	·004
Ni	"	"	"	"	"	none	"	none
Co	"	"	·1063	"	"	"	"	"
Fe	·010	·0006	·0042	·0038	·0011	·043	·007	·006
Zn	trace †	none †	none †	·0007	none		none	
Mn		none	none				"	
Si				none		·190		none
C					·0008	·013		
S		·013	none	·0020	·0004	·002		none
P					none			
Ca					"			
Na					"			
K					"			
Total	·025	·049	·165	·008	·003	·251	·031	·063

\* A blank opposite any impurity means that it was not looked for.

† Means platinum metals.

### 7. Conclusion.

It is now something over five years since the Geophysical Laboratory took up the task of redetermining the absolute temperature scale from 300° to 1100° with the nitrogen thermometer, and of extending it, if it should prove practicable to do so, to 1600° C., for it is in this upper region that most of the mineral relations which it is the chief purpose of the laboratory to study are found. Two preliminary publications have been made during the investigation. One, a brief summary of preliminary work up to 1100°, was given before the National Academy of Sciences and the American Physical Society in April, 1907,\* the second covered the same ground at con-

\* Abstract, Phys. Rev. xxiv, 531, 1907.

siderable length in 1908.\* The present paper extends the observations to  $1550^{\circ}$ , and completes the work contemplated under the original plan.

No attempt will be made to offer an inclusive summary of the whole investigation. It is a record of experimental measurements covering an unusually wide range of details which do not admit of brief classification. The errors which have heretofore been present in measurements with the nitrogen thermometer have been reduced by the present investigation to about one-fourth their former magnitude and the certainty of their evaluation is at least proportionately increased.

The chief source of present uncertainty is the temperature distribution over the surface of the bulb in an air bath. No indication of a limit to the temperature attainable with the nitrogen thermometer or to its ultimate accuracy was discovered during the present investigation.

The magnitudes of the errors, and their effects on the temperature, are summarized in Table IV, page 129. The determinations of the expansion coefficient of the bulb material (80 Pt: 20 Rh) are summarized on pp. 131–132.

The melting temperatures of the metals and salts which have been used as fixed points to establish the new scale are brought together in the table below, together with the conditions under which the determinations were made. The generally accepted Reichsanstalt scale is printed beside it for convenient comparison. The analyses of the metals are summarized on p. 159.

To this table has been added a new estimate of the melting temperature of platinum, of which we could make no direct determination. Its general acceptance and availability as a fixed point of reference, and the wide disagreement between the direct determinations heretofore made of it, form a sufficient reason for its inclusion. The estimate is arrived at in this way: There is a remarkably close agreement between independent determinations of the *temperature interval* between the melting points of palladium and platinum:

Nernst and von Wartenberg†	$204^{\circ}$
Holborn and Valentiner (at the Reichsanstalt)‡	$207^{\circ}$
Waidner and Burgess (at the Bureau of Standards)§	$207^{\circ}$

If we therefore simply add  $206^{\circ}$  to our determination of the palladium point, we obtain  $1755^{\circ}$  as the melting point of pure platinum, with an absolute error of perhaps no more than  $\pm 5^{\circ}$ . The table follows:

\* This Journal (4), xxvi, 405, 1908.

† W. Nernst and H. von Wartenberg, Ber. d. Deutsch. phys. Ges., iv, pp. 48, 146, 1906.

‡ L. Holborn and S. Valentiner, Ann. d. Phys. (4), xxii, 1, 1907.

§ C. W. Waidner and G. K. Burgess, Bull. Bur. Standards, iii, p. 163, 1907.

Substance	Point	Atmosphere	Crucible	Temperature	The Reich- sanstalt Scale
Zinc	Melting and freezing	Air	Graphite	418.2° ± 0.3	419.0*
Antimony	Do.	Carbon monoxide	Do.	629.2 ± 0.5	630.6
Silver	Do.	Do.	Do.	960.0 ± 0.7	961.5
Gold	Do.	Do.	Do.	1062.4 ± 0.8	1064.0
Copper	Do.	Do.	Do.	1082.6 ± 0.8	1084.1
Diopside (pure)	Melting	Air	Platinum	1391.2 ± 1.5	
Nickel	Melting and freezing	Hydrogen and Nitro- gen	Magnesia and Magne- sium Alum- inate	1452.3 ± 2.0	
Cobalt	Do.	Do.	Magnesia	1489.8 ± 2.0	
Palladium	Do.	Air	Pure Mag- nesia	1549.2 ± 2.0	1575.*
Anorthite (pure)	Melting	Do.	Platinum	1549.5 ± 2.0	

In addition, the following temperatures were incidentally obtained :

Cadmium	Melting and freezing	Air	Graphite	320.0 ± 0.3	321.7
Aluminum	Freezing	Carbon monoxide	Do.	658.0 ± 0.6	657.
Platinum	Melting	Air		1755.	

Geophysical Laboratory,  
Carnegie Institution of Washington,  
Washington, D. C., December 24, 1909.

\* Holborn and Valentiner, loc. cit.

ART. IX.—*A New Sclerometer*; by A. L. PARSONS (University of Toronto).

THE physical properties of minerals and metals have for a long time been a subject for investigation, and among the first of these properties to be studied were hardness and tenacity, but although the tensile strength and crushing point of the various substances are easily measured, the determination of hardness or resistance which a substance offers to abrasion is not so well understood. The sclerometer which was devised by Seebeck and later improved by Grailich and Peckarek is the one which is best known, but it is little used because the length of time which is required for a single measurement prevents the common use of an instrument which should be of valuable assistance to the mineralogist and metallurgist.

A bibliography of works on sclerometry is given by Jaggard\* which includes the most important papers and outlines the principles employed by various investigators in using their own instruments or those devised by others.

The new instrument differs from those of Seebeck, Grailich and Pekarek and others in that the force that is necessary to make a scratch is measured by means of a spring and not by weights.

*Description of the Instrument.*†

The instrument consists of four working parts on a base, as follows (see fig. 1):—

1. *Steel spring* (F) with test-point holder (H) fastened to the column (S).

2. *Object holder* (O) with divided horizontal circle (C), horizontal screw (1) for moving the object to be tested from side to side, and two vertical screws (2 and 3) to give the object the desired inclination.

3. Carriage (7) with transport screw (4) and spring (5) to move the test object, while making the scratch, and a slide (6).

4. Micrometer screw (E) and scale (8) to measure the elevation, which is proportionate to the force necessary to make a scratch.

5. Base (G) to hold the working parts together.

1. The spring (F) consists of a strip of steel 120<sup>mm</sup> long, from the column (S) to the test point, 4–8<sup>mm</sup> wide and 0.75<sup>mm</sup> thick. It is firmly fastened by a screw to the top of the

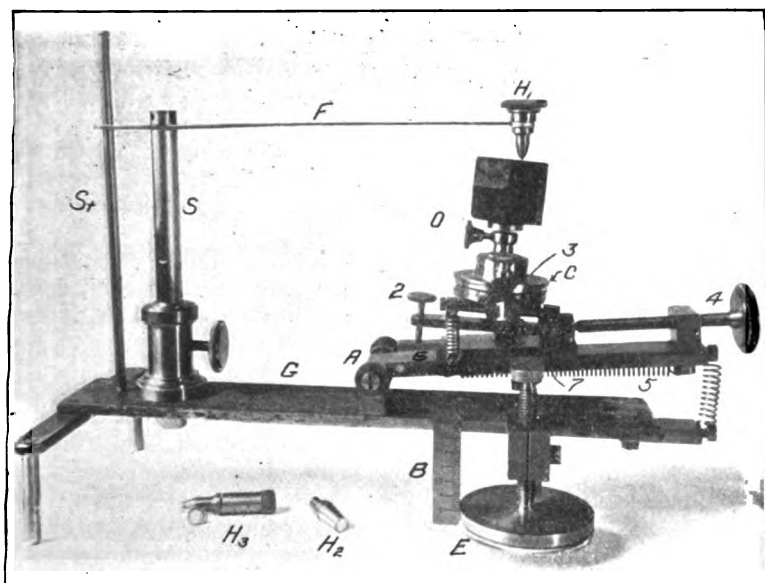
\* This Journal (4), iv, p. 399, 1897.

† Price of instrument, 80 marks from the mechanic, P. Stoe, Heidelberg, Germany, Jubilaums Platz, 70.

column (S) and with this can be raised or lowered in the socket (B). The rod (St) behind the column prevents lateral movement of the spring in raising or lowering the same. On the free end of the spring is screwed the test point holder ( $H_1$ ,  $H_2$ , or  $H_3$ ) which carries the crystal point or metal point with which the test object is to be scratched.

The following three point-holders seem desirable and are provided with the instrument:  $H_1$  with diamond point. This is preferably a tetrahedral cleavage fragment, as this form gives

FIG. 1.



the sharpest cutting edge and is least liable to variations in hardness.  $H_2$ , a holder in which a needle of steel or other metal can be fastened. Generally a sewing needle is used, as there is little variation in hardness in needles from the same packet. For very soft substances a brass pin or a copper point may be employed.  $H_3$ , a holder with a cup-like depression in which a crystal or other substance may be fastened by means of wax "kit."\* This may be either a substance of *known* hardness with which another is to be compared or one of *unknown* hardness which is to be tested by scratching the surface of a substance whose hardness is known.

\* A piece of "kit" is provided with each instrument.

2. The object carrier (O) holds the crystal or other test object firmly in the position desired for making the tests. The crystal is fastened by wax "kit" to a small plate which is set in a socket at the top of the carrier.

The adjustment of the test object is as follows:

1. To bring the surface under the test point the transport screw (4) and the screw (1) are used. The screw (1) has also the purpose of moving the test object from side to side so that duplicate measurements may be made in parallel positions.

2. To give the face of the test object the desired inclination so that it forms with the slide (6) a wedge, it is tilted by means of the screw (2). The inclination will vary according to the hardness of the substance to be tested; very soft substances require only a slight inclination while harder materials require a greater one. This inclination of the surface to be tested is one of the most important features of the instrument, as it gives the measure of the pressure of the spring (F) when the crystal is moved by the transport screw (4).

3. To level the test object from side to side a screw (3) on the rear of the instrument is employed.

4. To test the hardness of the substance under investigation in different directions the graduated circle (C) is turned about its axis. This circle is divided into 36 parts so that each division gives  $10^\circ$ .

3. The transport screw (4) and accompanying spring (5) move the test object under the test point. The inclination of the surface to be tested to the plane of the slide (6) forms a wedge which by the movement of the screw (4) raises the spring (F) until a scratch is made.

4. The micrometer screw (E) raises or lowers the test object until it just touches the test point. Each division on the screw head measures an elevation of  $0.01^{\text{mm}}$ .

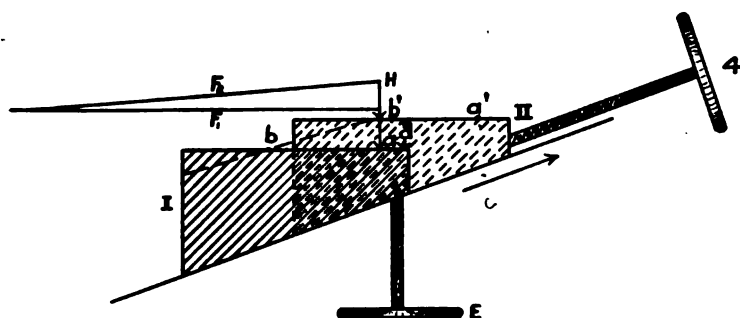
5. The base (G) carries the different parts and needs no particular description.

### *Measurement.*

The crystal or other test object is fastened to the top of the object holder (O) and inclined by means of the screw (2) so that the face to be investigated forms a wedge with the track (6). By the screw (3) it is made horizontal from side to side. By raising or lowering the column (S) the test point is brought to a position where it nearly touches the surface to be tested. By means of the micrometer screw the crystal is then raised until the test point just comes in contact with the face to be tested at the point *a*, fig 2.

Now by means of the transport screw (4) and the accompanying spring (5) the crystal is moved in the direction indicated by the arrow points so that as the surface acts as a wedge the test point (H) is raised and the spring (F) is bent from position  $F_1$  to position  $F_2$ . By this movement a position is reached where the test point makes a scratch on the surface to be tested which is indicated in the figure as  $b$ . By the movement of the test object from position I to position II this point  $b$  has been brought to the position  $b'$  and the point  $b$  has also been raised the distance  $ab' = d$ . After the scratch has been made a reading is made on the micrometer screw E. The crystal is then lowered by means of the micrometer screw

FIG. 2.



until the test point just touches the crystal or other substance at the point  $b'$ , in other words at the beginning of the scratch, and a second reading is made on the micrometer screw which gives the distance  $ab'$  in divisions on the micrometer screw. This distance gives a measure of the bending of the spring or of the pressure necessary to make a scratch on the crystal, that is, it is a measure of the hardness.

In practice the lowering of the crystal by means of the micrometer screw gives a forward motion of the crystal in the direction of the arrow points in the figure and the beginning of the scratch must be brought under the test point by the transport screw (4). It is also found better in practice to lower the crystal or other test object so that the test point does not touch the surface, and then raise the test object again until the point just touches.

#### Calibration.

In this instrument the force that is necessary to make a scratch is measured by the strain on the spring (F) and the



reading is made in divisions on the micrometer screw (E). In the instruments of Seebeck and others this same force is measured by the weights with which the test point is loaded. This measurement by weights has the advantage that the weights are constant, while the bending of the spring (F) is dependent upon the material and dimensions of the same, and with each instrument we get a different factor. In order to reach comparable results it is necessary to reduce the divisions on the micrometer screw to measures of weight. This reduction of elevation to weight is called the *calibration of the instrument*.\*

The calibration of the instrument is made in this way. A glass plate is fastened to the object carrier and a scratch is made with the diamond point. The glass is now brought to the position where the test point just touches the beginning of the scratch. This point is determined when the test point just meets its reflection in the glass. The reading on the micrometer screw (E) is taken, the plate lowered by means of the micrometer screw and a weight placed on the test point holder (H) by which the spring is bent. The plate of glass is now raised until the test point just touches the beginning of the scratch and a second reading is made on the micrometer screw (E). Subtracting the second reading from the first gives the number of divisions on the micrometer screw that corresponds to a given weight.

By lowering the glass plate by means of the micrometer screws not only the plate but the track (6) and the object carrier (O) describe a small arc of a circle about A so that the beginning of the scratch must be brought under the point by means of the transport screw (4).†

The deflection of the spring for various weights is measured and a table can be made for all.

The results of the calibration are as follows:

	Weight	Reading	Deflection of needle in divisions of graduated circle	No. of divisions equivalent to 1 gm.	Mean No. of divisions equivalent to 1 gm.
	gm.				
First trial..	0	183.0	0		
	5	170.0	13	2.6	
	10	159.0	24	2.4	
	20	134.5	48.5	2.425	
	50	60.5	122.5	2.45	2.469

\* Every instrument is furnished with a calibration table so as to give the weight that corresponds to one division on the micrometer screw.

† A very slight error is thus introduced but in practice this can be neglected, as the determinations of hardness are made in the same way and the errors are comparable.

	Weight gram.	Reading	Deflection of needle in divisions of graduated circle	No. of divisions equivalent to 1 gram.	Mean No. of divisions equivalent to 1 gram.
Second trial.	0	211.5	0		
	5	199.0	12.5	2.5	
	10	186.5	25.0	2.5	
	20	162.5	49.0	2.48	
	50	86.0	125.5	2.51	2.4975
Third trial.	0	135.0	0		
	5	123.0	12.0	2.4	
	10	110.0	25.0	2.5	
	20	85.0	50.0	2.5	
	50	7.0	128.0	2.56	2.49
Fourth trial.	0	193.5	0		
	5	180.5	13.0	2.6	
	10	168.5	25.0	2.5	
	20	143.5	50.0	2.5	
	50	67.0	126.5	2.53	2.5325
Mean of all .....					2.4975

The results agree closely so that the elevation may be considered proportional to the weight and in this instrument a load of 10 grams is equivalent to 25 divisions on the micrometer screw.

### *Results of Measurements.*

Plane and polished surfaces of glass, iron, copper, and brass were taken as test objects. A few trials were made with crystal faces, but further study is necessary before it can be stated that the instrument is suitable for determining the hardness of unpolished surfaces.

*Measurements with the diamond point* (a tetrahedral cleavage fragment):

A. *Copper*. 10 measurements: Pressure = 1.2, 1.2, 1.8, 1.6, 1.6, 1.4, 1.6, 1.8, 2.0, 1.4 gram. Mean of first five measurements = 1.48 gram.; mean of second five measurements = 1.44 gram.; mean of all 1.46 gram.

B. *Brass*. 10 measurements: Pressure = 1.6, 2.0, 2.2, 2.2, 2.0, 2.2, 2.2, 2.2, 1.6, 1.7 gram. Mean of first five measurements = 2.00 gram.; mean of second five measurements = 1.98 gram.; mean of all 1.99 gram.

C. *Iron* (rolled). 10 measurements: Pressure = 2.2, 1.8, 2.0, 1.6, 2.2, 2.0, 2.2, 1.8, 2.0, 1.8 gram. Mean of first five measurements = 1.96 gram.; mean of second five measurements = 1.96 gram.; mean of all 1.96 gram.

D. *Glass* (object glass for microscope). 10 measurements: Pressure = 3.8, 4.0, 4.2, 4.0, 4.0, 3.8, 4.2, 4.2, 4.2, 4.4 gram.

Mean of first five measurements = 4.0 grm.; mean of second five measurements = 4.16 grm.; mean of all 4.08 grm.

*Measurements with steel point* (sewing needle, number 5 sharp):

E. *Copper*. 10 measurements: Pressure = 5.0, 4.8, 4.0, 4.8, 4.0, 4.2, 3.8, 4.2, 4.2, 4.0 grm. Mean of first five measurements = 4.52 grm.; mean of second five measurements = 4.08 grm.; mean of all 4.3 grm.

F. *Brass*. 10 measurements: Pressure = 16.4, 12.0, 10.4, 10.4, 9.8, 14.0, 13.0, 10.8, 10.8, 10.4 grm. Mean of first five measurements = 11.8 grm.; mean of second five measurements = 11.8 grm.; mean of all 11.8 grm.

The ten measurements were made each time on the same piece of copper, brass, etc. with the same inclination of the surface and the same direction for the scratch. After each scratch the plate was moved a little to one side by means of the screw (1) so that the ten scratches were parallel and near each other.

The beginning of the scratch with the diamond point was always sharp and easily seen and is a very distinct point. With the steel needle, however, the beginning of the scratch on steel was somewhat uncertain. The scratch did not have a sharp beginning but was microscopic and gradually increased in depth with the increase of pressure.

In general a diamond point will probably give the best results for all substances except possibly for those which are extremely soft. Special study is being made to determine this point.

The nearly equal results obtained by scratching iron and brass with diamond were surprising and the two were tested against each other. The iron made a scratch on the brass very easily and the brass made a scratch on the iron but apparently with greater difficulty, but the point on the iron was, however, sharper than the point on the brass. It would appear that in the determination of hardness other properties such as tenacity, elasticity, flexibility, etc. must be taken into consideration, and it is hoped that this instrument may be of assistance in the study of the relations between these properties.

The results show a good determination when the mean of five measurements is taken.

The measurement is rapid and requires less than three minutes for a measurement when the test object is in position or for ten consecutive measurements less than a half hour.

*The advantages* of the instrument above mentioned are rapidity of observations, compactness, and cheapness. So far as observations have been made up to the present time, the instrument gives good results for polished faces of glass and metal, but further study is necessary to show its availability for minerals.

Heidelberg, Aug. 14, 1909.

ART. X.—*Dodecahedral Jointing due to Strain of Cooling*; by FRED. H. LAHEE.

IN the woods just south of Beacon St., and about a quarter of a mile west of Hammond St., Chestnut Hill, Mass., the Roxbury conglomerate is cut by a fine-grained, basaltic dike\* which, in some parts, disintegrates into small (average diameter,  $\frac{1}{8}$  in.), polyhedral, often roughly dodecahedral, fragments. The dike has approximately plane-parallel sides, is four feet thick, strikes N. 20° E., and dips 78° E., its attitude being parallel to a prominent joint set of the country rock. That it entered a relatively cool rock is indicated by the fact that its texture, moderately fine in the middle, becomes very fine at the contact. It contains occasional large phenocrysts (xenocrysts) of apatite and biotite, both of which are well shaped, and of pink acid feldspar, which has outlines made irregular by the invasion of short tongues of the groundmass.

Near the country rock, on each side, in a zone from four to ten inches wide, hexagonal columnar jointing is poorly developed perpendicular to the contact surface. Inwards, the columns give place to the polyhedral blocks already mentioned as conspicuous in the disintegration of the rock.

Obviously the joints† which give rise to such many-sided fragments are of small extent. Furthermore, they (the joints) often vary in direction, or may die out entirely; but in spite of this irregularity, it is not difficult to find blocks bounded by twelve rhombohedral faces that intersect one another at angles nearly equal to the similar angles of a perfect dodecahedron. The surfaces of the blocks are relatively coarsely granular, without a well-developed feather fracture, a feature not uncommon on the more finely textured hexagonal columns. Where the phenocrysts are in the path of fracture, the break either passes round the obstacle, or takes advantage of the mineral cleavage. These statements clearly point to the inference that the dodecahedral jointing, like the hexagonal, is an effect of tension due to cooling.

Hexagonal columnar jointing has long been so interpreted. In the ideal case, according to the principles of least action, the columns begin their development as a series of three-way fractures (each fissure at an angle of 120° to the other two) radiating from equally spaced points in a surface which is perpendicular to their (the columns') direction of growth. This type of fracture is therefore a two-dimensional, or surface, phenomenon, and the extension of the columns may be regarded

\*The writer wishes to thank Mr. R. W. Sayles for bringing this dike to his notice, and Professor Chas. Palache and Professor J. B. Woodworth, who discovered the dodecahedral jointing, for valuable suggestions.

†Similar jointing has recently been seen by the writer in trap dikes on Ragged Island, Casco Bay, Maine.

as the result of the regular inward advance of successively cooler planes, for each of which the temperature is uniform throughout.

If, on the other hand, we conceive of a *solid* which is losing heat equally in all directions and in such a way as to be subjected to a homogeneous strain, *six-way* fracture will develop instead of the *three-way* fracture of the cooling surface, and the resulting geometrical form will be a *dodecahedron* instead of a *hexagon*.

As hexagonal fracture may be illustrated by considering a series of equal tangent circles compressed uniformly from all directions in the same plane, so dodecahedral jointing may be experimentally demonstrated by subjecting a group of equal tangent balls, arranged in superposed horizontal layers, to equal pressure from every direction. Those spheres which were originally in contact with twelve others will, it is true, be dodecahedral; but whether they become regular rhombic dodecahedra or forms which, to borrow from crystallography, resemble a regular rhombic dodecahedron twinned parallel to an octahedral face, will depend on whether the centers of the balls of a given horizontal layer were above the centers of the spaces, or of the spheres, of the second layer below. In either case, prior to the compression, the conditions of unoccupied space and of equal distance between the centers of spheres will be fulfilled.

The literature appears to be lacking in references to the particular kind of jointing described. Much of the work on this subject was done several decades ago. At that time hexagonal jointing received considerable attention and was correctly explained as the result of uniform strain in a surface. Spheroidal structure, which was shown by Bonney to be often unrelated to fracture systems, was, however, held to be the analogous phenomenon in a solid, and perlitic structure was consigned to the same category. Bonney thus states his views:\* "A hexagon is the figure which will result from uniform contraction in two dimensions, a sphere from contraction in three dimensions." The case in point, however, leads to the conclusions: (1) that hexagonal columnar jointing is caused by equal tension in all directions in a surface at right angles to which the strain is differential; and (2) that uniform contraction in a solid must, under corresponding conditions of homogeneity, give rise to dodecahedral jointing. The sphere cannot be the exact analogue of the hexagon.

Cambridge, Mass.

\* Bonney, T. G., On Columnar, Fissile, and Spheroidal Structure. *Quart. Jour. Geol. Soc., Lond.*, xxxii, p. 152, 1876. On this subject see also Jukes, J. B., and Geikie, A., *Student's Manual of Geology*, 3d ed., 1872, pp. 182, 183, 311; Mallet, R., *Phil. Mag.*, Ser. 4, vol. i, pp. 122, 201; Scrope's *Volcanoes of Central France*, p. 92; Iddings, J. P., *The Columnar Structure in the Igneous Rock on Orange Mountain, New Jersey*, this *Journal*, (3), xxxi, p. 321, 1886, and Iddings, J. P., *Igneous Rocks*, N. Y., 320, 1909.

ART. XI.—*Restoration of Paleolithic Man*; by RICHARD SWANN LULL. (With Plate I.)

[Contribution from the Paleontological Laboratory, Peabody Museum, Yale University.]

AN attempt has recently been made by the writer to restore in plastic form the type of mankind dwelling in Europe during a portion of the Paleolithic period and variously known to science under the names of *Homo primigenius*, *neanderthalensis* or *mousteriensis*. The restoration, which is life size, is a tentative one and will be kept in the clay for a time in order that authoritative criticism may be met before it is cast in plaster (cf. Plate I).

The model is based mainly upon what is known as the "Man of Spy No. 1"; one of the two specimens found at Spy in Belgium, of which the museum contains excellent plaster casts. The illustrations of the remains of man found at Krapina in Croatia and described by Professor Gorjanovic-Kramberger in his "Der Diluviale Mensch von Krapina in Kroatien" 1906, were largely used, together with certain other measurements, such as the estimate for total height, etc. For the use of the casts and the assembling of data, together with kindly criticism, I am indebted to Dr. George Grant MacCurdy, Curator of Anthropology in this museum, while to Professor Joseph Barrell, who has taken a very lively interest in the work, I wish also to acknowledge my gratitude.

My conception of *Homo primigenius* is that of a man of low stature, standing only five feet three inches in height, but of great physical prowess as indicated by the robustness of the limb-bones and especially of their articular ends. The great paunch of the higher anthropoid apes, which are almost exclusively vegetarians, is lacking and in its place is shown the clean-cut, athletic form of torso such as one sees in the typical North American Indians, for I imagine food conditions were much the same. We have abundant evidence that Paleolithic man was a crafty hunter, for the remains of various animals which he slew for food are found in the bone breccias of the caverns wherein his own relics are entombed. Great power is indicated, however, in the upper portion of the trunk and in the arms, compensating this ancient type for his lack of adequate tools and weapons.

The knees are somewhat flexed as the curved thigh bone would indicate, and probably should be more so, and the trunk is only partially erect, for the inward curves of the back bone, so characteristic of modern man, are but feebly developed, as in the case of babes of the present day or in individuals bowed down by the weight of years. The shin is relatively short, as with certain present-day races, and the great toe somewhat offset though having long since lost its ape-like opposability.

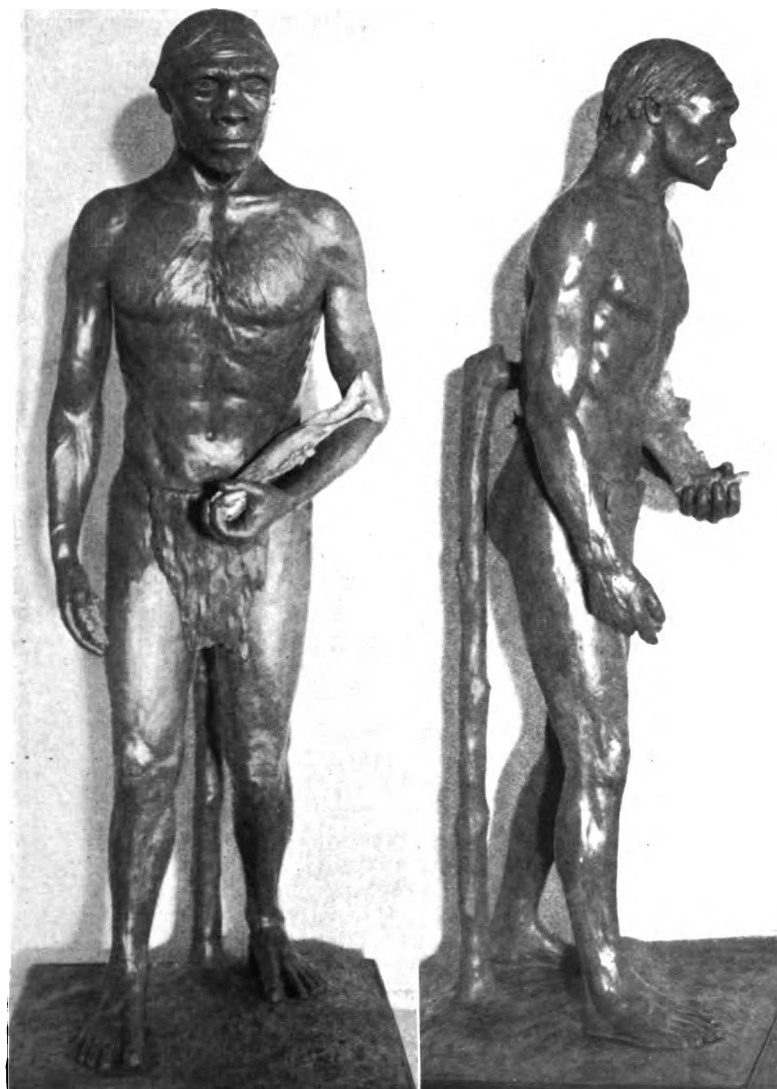
The head shows the prominent supra-orbital ridges above the deep-set eyes; the low, flat forehead; the broad, concave, nasal bridge and the somewhat prognathous jaws. The lower jaw is deep and powerful, and lacks the characteristic chin prominence of modern man. Other restorations give a greater prognathism than mine, and it may be that here I am in error in showing too great a refinement of countenance as compared with the low type of calvarium. The contour of the jaw is based upon actual measurement of one of the Krapina specimens and one should bear in mind that the far older jaw recently brought to light at Heidelberg, though of a more brutal type than any yet known, shows less dental prognathism than do the modern negroes, indicating a very great antiquity for the radiative evolution of the several human stocks.

In all probability the men of that day were much more hairy than the model would indicate, as they had little or no clothing and the climate, during part of their racial career at least, was severe. They were, however, cave dwellers and knew the use of fire. I have purposely refrained from indicating this conjectural character, as it would, to a certain extent, conceal the conformation of the underlying parts.

A jaw of the cave bear, *Ursus spelæus*, a contemporary animal, though now long since extinct, is borne in the left hand, while the right contains a chipped stone implement from one of the typical stations, thus indicating the cultural plane of the race.

This type dwelt in Europe before the last glacial period, estimated at from 100,000 to 200,000 years ago, and continued for a long period of time, for his remains are found entombed successively with both cold and warm climate animals. The relics are found within or near rock shelters and caves, the best known of which are those of Neanderthal, Germany; Spy, Belgium; Krapina, Croatia; Le Moustier and La Chapelle-aux-Saints in France. As a race *Homo primigenius* is to-day entirely extinct, though whether he was blotted out or absorbed by the invading horde of the superior *Homo sapiens* we have no certain knowledge. Occasionally, however, something of his type appears in modern man, notably in St. Mausborg, a medieval Bishop of Toul, and in Lykke, a scientific Dane of the eighteenth century, as well as among Australians and Melanesians, the lowest living races of mankind. These may be looked upon as instances of atavistic reversion.

The "Man of Spy," while showing more pithecoïd characters than his successor, was nevertheless eminently human, representing as he does the type just preceding modern man, and one far removed from a true ape-like ancestry. In the popular conception "Prehistoric man" should be gorilloïd, or at any rate distinctly simian; against this misconception the model stands as a silent protest.



RESTORATION OF PALEOLITHIC MAN.





ART. XII.—*Bismite*; by W. T. SCHALLER and  
F. L. RANSOME.

IN the Goldfield district in Nevada, bismite occurs in the January, Combination, Sandstorm, and probably also in other mines, as minute, pearly scales with brilliant luster and of silvery whiteness. The luster of the scales is almost metallic and suggests at first glance delicate and untarnished crystals of native silver. The mineral is limited to the oxidized zone, is usually accompanied by limonite and is frequently associated with rich ore. It occurs as single glittering scales or specks on the walls of cavities in spongy limonite or rusty ledge-matter, as delicate frost-like films on the same materials and as spongy aggregates with quartz. In the last-named form it is clearly pseudomorphous after bismuthinite, the material having consisted originally of a mass of bismuthinite prisms held together by a siliceous gangue. The prismatic structure of the bismuthinite is retained as hollow casts in the quartz, lined or partly filled with scales of bismite.

As natural crystals of bismite do not appear to have been found hitherto and as the mineral has been assigned to the orthorhombic system in Dana's and Hintze's mineralogies on the basis of Nordenskiöld's work on artificial crystals in 1860 and 1861, considerable interest attaches to the Goldfield occurrences on account of the crystallinity of the material.

When examined under the microscope in gently powdered material the crystals appear as thin colorless scales, with occasionally a suggestion of hexagonal outline. On account of their tenuity, it is rare that an edge view of a scale is obtainable. The larger flat-flying scales are dark in all positions between crossed nicols and give a negative uniaxial figure with convergent light. There are no colored rings and the double refraction is apparently not great. The refractive index, on the other hand, is rather high, being greater than that of anorthite. The mineral has a perfect basal cleavage and the scales, viewed without the analyzing nicol, commonly show delicate interference colors due to the refraction and reflection at the surfaces of the exceedingly thin cleavage sheets.

Some of the best material obtainable was analyzed with results as follows:

Insol. in HCl, mostly quartz gangue .....	1	2	3	Average
Bi <sub>2</sub> O <sub>3</sub> .....	78.95	78.87	79.01	78.94
H <sub>2</sub> O (loss on ign.) .....	17.29	17.00	16.84	17.04
Fe <sub>2</sub> O <sub>3</sub> .....	3.96	----	----	3.96
	0.36	0.50	0.21	0.36

---

 100.30

The results show that the mineral is either bismite or else a hydrous oxide of bismuth. If the latter be the case, the mineral is a new species (providing, of course, that  $\text{Bi}_2\text{O}_3$  is the correct formula for the bismuth ocher found in nature and called bismite). Attempts to isolate a sufficient quantity of the pearly scales from the gangue for separate analysis were not successful.

The minute, tabular crystals are too incomplete to allow of a determination of their geometrical form by crystallographic measurements alone. From the uniaxiality of the crystals, their hexagonal outline, triangular markings on the base and distribution of the faces as far as seen, reference of them to the rhombohedral division of the hexagonal system appears to be justifiable.

The value of the  $c$  axis, derived in a manner presently to be described, is 0.5775. Seven faces are determined as present; the base, five positive and one negative rhombohedra. Besides these, there are indications of two more positive rhombohedra. A brief description of these forms follows.

$c \{0001\}$ . Always very large, even, and highly polished. Sometimes shows triangular markings or striæ, the faces parallel to these markings being taken as positive.

$o \{10\bar{1}6\}$ . Occurs on two crystals, as broad faces giving, however, poor reflections. One face was considerably striated, giving two signals a degree apart.

$q \{10\bar{1}5\}$ . Broad faces giving fairly good reflections.

$u \{10\bar{1}4\}$ . Narrow faces, one striated with a fair reflection, and one as a line face giving a very poor reflection.

$k \{10\bar{1}3\}$ . Usually as a line face, striated and giving a very poor reflection.

?  $\{20\bar{2}5\}$ . A doubtful face, narrow, giving no distinct signal.

?  $d \{10\bar{1}2\}$ . Another doubtful face, broad, giving no distinct reflection.

$y \{20\bar{2}1\}$ . Line faces, giving exceedingly faint reflections.

$z \{01\bar{1}1\}$ . The only negative rhombohedron observed. Very faint line faces, giving no reflection. Its negative position could be determined only on crystal No. 6.

The measurement of the forms are shown below.

		Meas.	Calc.
(0001) :	(10 $\bar{1}$ 6)	6° 37'	6° 41'
" :	(10 $\bar{1}$ 5)	7 33	7 36
" :	(10 $\bar{1}$ 4)	9 31	9 31
" :	(10 $\bar{1}$ 3)	12 11	12 26
		13 18	12°-14°
" :	(20 $\bar{2}$ 1)	54°	54°
" :	(01 $\bar{1}$ 1)	35°	32½°
			53 08
			33 42

Doubtful forms:	Meas.	Calc.
(0001) : (2025),	15°	14° 56'
" : (1012),	16°-20°	18 26

The value for the  $c$  axis was obtained from three measurements that were considered as the most accurate. The others gave values agreeing fairly well with the one adopted, as is shown below. The crystals were measured on the two-circle goniometer and the  $\rho$  angle for these forms is the angle between that form and the base.

The three best measurements are:

$\rho \{10\bar{1}5\} = 7^\circ 33'$	$p_o = \cdot 6627$	cryst. No. 1
$\rho \{10\bar{1}5\} = 7 \ 36$	" = $\cdot 6672$	" " 4
$\rho \{10\bar{1}4\} = 9 \ 31$	" = $\cdot 6706$	" " 2

$$\text{Av. } p_o = \cdot 6668 ; c = 0.5775.$$

An average of the other measurements gave values closely agreeing. Thus:

$\rho \{10\bar{1}6\} = 6^\circ 37'$	$p_o = \cdot 6960$	cryst. No. 3
" = 6 41	" = $\cdot 7031$	" " 6
$\rho \{10\bar{1}4\} = 9 \ 31$	" = $\cdot 6706$	" " 6
$\rho \{10\bar{1}3\} = 12 \ 11$	" = $\cdot 6477$	" " 6
" = 12 26	" = $\cdot 6614$	" " 4
" = 13 18	" = $\cdot 7102$	" " 1

$$\text{Av.} = \cdot 6815$$

The following measurements of faces giving no distinct reflections also showed close agreement:

$\rho \{10\bar{1}3\} = 12^\circ-14^\circ$ (av. $13^\circ$ )	$p_o = \cdot 69$	cryst. No. 1
$\rho \{2025\} = 15^\circ$	" = $\cdot 67$	" " 2
$\rho \{10\bar{1}2\} = 16^\circ-20^\circ$ (av. $18^\circ$ )	" = $\cdot 65$	" " 1
$\rho \{01\bar{1}1\} = 35^\circ$	" = $\cdot 70$	" " 5
" = $32\frac{1}{2}^\circ$	" = $\cdot 64$	" " 6
$\rho \{2021\} = 54^\circ$	" = $\cdot 69$	" " 1
" = $54^\circ$	" = $\cdot 69$	" " 6

The values for  $p_o$  just given show that the interpretation of the forms is the correct one.

Of the six crystals (all incomplete) that were measured, only two need to be briefly described.

Fig. 1a is an orthographic projection of a crystal (No. 1), showing the trigonal distribution of the rhombohedra, and the triangular markings on the base.

Fig. 1b shows a similar projection of cryst. No. 6, with a negative rhombohedron.

An odd feature of these crystals is that the development of the faces is so uneven, that no two faces of the same form are present on the upper half of a crystal, though this is in part due to the incompleteness of each crystal.

From the foregoing observations it appears that the natural bismite is not orthorhombic but belongs to one of the uniaxial

FIG. 1a.

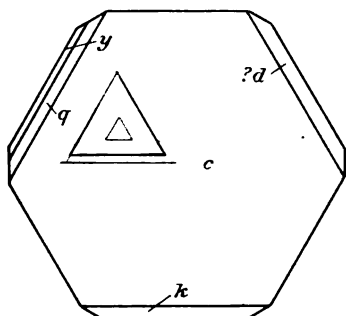
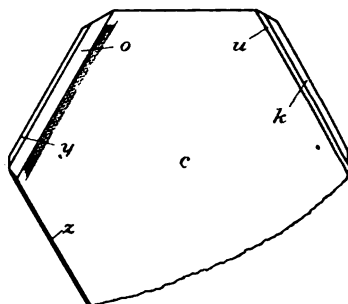


FIG. 1b.



systems, probably the hexagonal. Its presence in oxidized ore appears to be uniformly indicative of bismuthinite in the original sulphide ore. Some migration, however, has taken place during oxidation and the scales of bismite do not always occupy the exact positions of the parent needles of bismuthinite.

U. S. Geological Survey,  
Washington, D. C.

ART. XIII.—*Contributions to the Mineralogy\* of Franklin Furnace, N. J.*; by CHARLES PALACHE.

THE purpose of this paper is to present in brief form some of the more interesting results obtained in the study, continued through several years, of the minerals of Franklin Furnace, New Jersey. The complete results of the study will, it is hoped, appear soon in monograph form, but it seems desirable to place on record without further delay the chemical analyses made for the most part in the laboratory of the Geological Survey. These analyses are either of minerals not before recorded from this locality or of species concerning which our information is incomplete. With these are also included crystallographic notes on a number of species and a list of additional minerals whose presence at Franklin Furnace has not hitherto been recorded.

*Arsenopyrite: Crystal Form, Composition.*

Brilliant crystals of arsenopyrite up to an inch in length were found in several of the limestone quarries at Franklin Furnace in 1905. They are associated with pyrite, pyrrhotite, spinel, humite, tourmaline and phlogopite. The crystals are completely developed, showing besides known forms the new pyramids (532), (112), (143), and (132), the first present on all crystals and characteristic for the locality.

The following analysis by E. C. Sullivan, U. S. G. S., was made of selected crystal fragments:

		Ratio	
Fe .....	32.48	.581	} 1
Co .....	1.16	.02	
As .....	48.72	.650	1.08
S .....	18.80	.587	.98

The ratio shows a normal composition. The presence of cobalt is interesting; it has been shown by Kraus & Scott† to be present in about the same proportion in pyrite crystals in the same limestone. Tests for cobalt made on the associated pyrrhotite showed no trace of this element and hardly more than a trace of nickel.

*Fluorite: Composition.*

The following analysis of fluorite by G. Steiger, U. S. G. S., was made in the belief that it was a manganiferous variety.

\* Published by permission of the Director of the U. S. Geological Survey.

† Zeitschr. für Kryst., xlv, 144, 1907.

The material was pale red and granular, the matrix of franklinite grains.

Ca .....	51.21	Al .....	0.18
Mg .....	0.24	F .....	45.85
Fe .....	0.27	Cl, Co <sub>2</sub> .....	none
Mn .....	0.09		
			<hr/> 97.84

Mr. Steiger remarks that the deficiency in the analysis is doubtless due to fluorine.

The manganese content is insignificant. If the total deficiency, 2.16 per cent, is calculated as fluorine, there is still slightly less than is required to form  $RF_2$  with all bases, but almost exactly enough to satisfy the calcium. This suggests, but of course does not prove, that the bases other than calcium are present as impurities in the form of unknown compounds.

*Manganosite: Occurrence, Composition.*

This rare substance, known hitherto only from two Swedish localities, was found in a single specimen in the Harvard Mineralogical Museum. The specimen consists of a granular aggregate of franklinite, zincite and manganosite. The latter is in irregular grains showing cubic cleavage, dark green in the mass, emerald-green in thin fragments. The material analyzed contained traces of zincite and minute black films of manganese oxide. The specific gravity was 5.364.

1. Manganosite: analysis by George Steiger, U. S. G. S.
2. Same corrected for ZnO and MnO, known to be present.

	1	2
MnO .....	94.59	99.61
MnO <sub>2</sub> .....	1.30	----
ZnO .....	3.41	----
FeO } .....	0.26	0.27
Fe <sub>2</sub> O <sub>3</sub> }		
MgO .....	0.11	0.12
H <sub>2</sub> O - .....	0.38	----
H <sub>2</sub> O + .....	0.40	----
	<hr/> 100.45	<hr/> 100.00

The material is thus shown to be very nearly of the theoretical composition of manganosite, MnO.

*Zincite: Crystal Form.*

Measurements of natural crystals of zincite are very few and poor and the generally accepted axial ratio for the species is based on artificial crystals. The writer obtained measurements

on one crystal of zincite from Franklin Furnace, however, which were very satisfactory; he has therefore calculated an axial ratio based on them and in the following table gives all the measurements made on natural crystals and the corresponding angles calculated from (1) the new ratio, (2) Dana's ratio, (3) Traube's ratio based on artificial crystals. The author's measurements were on four faces of the pyramid (4045), the angle to the base (average) being  $55^{\circ} 42'$  with deviation of but  $4'$ . A single reading (0001) to (10 $\bar{1}$ 1) was also obtained, in close agreement.

Angle	Calculated			Measured				
	Dana $a:c=$ 1:1.6219	Traube $a:c=$ 1:1.6077	Palache $a:c=$ 1:1.5870	Dana '86	Grosser '92	Moses '95	Palache	
							Contact	Reflexion
0001 $\wedge$ 10 $\bar{1}$ 1	$61^{\circ} 54'$	$61^{\circ} 41'$	$61^{\circ} 23'$	----	----	----	$62^{\circ} 00'$	$61^{\circ} 22'$
10 $\bar{1}$ 1 $\wedge$ 01 $\bar{1}$ 1	52 21	52 14	52 04	----	----	----	52 00	* ----
0001 $\wedge$ 4045	56 17	56 03	55 42	----	$55^{\circ} 38'$	$55^{\circ} 40'$	----	$55^{\circ} 42'$
4045 $\wedge$ 04 $\bar{4}$ 5	49 09	49 00	48 48	----	48 50	----	----	----
0001 $\wedge$ 5054	66 52	66 41	66 25	$65^{\circ} 20'$	----	----	----	----
5054 $\wedge$ 0554	54 46	54 40	54 33	53 53	----	$54^{\circ} 42'$	----	----

*Gahnite, variety Dysluite: Composition.*

Following is an analysis of a gahnite crystal supplied by Mr. Canfield from the locality at Sterling Hill which yielded the enormous crystals in the Canfield Collection. This is the type of the variety dysluite but has not been before analyzed. Specific gravity 4.56.

1. Analysis of dysluite, W. T. Schaller, U. S. G. S., 1906.
2. Same omitting  $\text{SiO}_2$ ,  $\text{CO}_2$  and equivalent of  $\text{CaO}$ , and  $\text{H}_2\text{O}$ . State of oxidation of iron and manganese not known.

	1	2	Mol. Ratio	
$\text{Al}_2\text{O}_3$ .....	47.27	48.81	.478	} $.542 = 1$
$\text{Fe}_2\text{O}_3$ .....	9.90	10.22	.064	
$\text{ZnO}$ .....	37.10	38.31	.472	} $.523 = 1.04$
$\text{MnO}$ .....	0.93	0.97	.013	
$\text{MgO}$ .....	1.09	1.12	.028	
$\text{CaO}$ .....	1.01	0.57	.01	}
$\text{CO}_2$ .....	0.38	----	----	
$\text{SiO}_2$ .....	1.47	----	----	
$\text{H}_2\text{O}$ .....	1.21	----	----	
	100.36	100.00		

The composition of dysluite is very like that of the gahnite from Franklin Furnace analyzed by Brush, both being very high in zinc.



*Franklinite: Form, Composition.*

Small implanted crystals of franklinite of quite abnormal appearance were seen in two specimens believed to have come from the Hamburg mine, Franklin Furnace. The crystals are of adamantine luster and on edges or where splintered show a deep red color. The prevailing habit is cubo-octahedral with occasional planes of the forms (101), (311), (211) and (310). The unique color and habit of these crystals suggested a new type of the spinel group, but the analysis below by W. T. Schaller, U. S. G. S., shows them to be of ordinary franklinite composition. Specific gravity 5.09.

*Fe <sub>2</sub> O <sub>3</sub> .....	66.58	CaO.....	0.43
*MnO.....	9.96	MgO.....	0.34
ZnO.....	20.77	H <sub>2</sub> O.....	0.71
			99.51

*Hetærolite: Form, Composition.*

Reëxamination of this mineral, which has been a doubtful species because of Moore's incomplete description, establishes the correctness of his characterization as a zinc hausmannite.

Tetragonal, shown by optical behavior of the fibers under the microscope. Indistinct prismatic cleavage, specific gravity 4.85.

Composition ZnO.Mn<sub>2</sub>O<sub>3</sub>, as shown by the following analysis of material furnished by E. P. Hancock:

1. Hetærolite, analysis by W. T. Schaller, U. S. G. S., 1906.
2. Same corrected for the small amount of SiO<sub>2</sub> and for water probably contained in a slight admixture of chalcophanite.

	1	2	Ratio.
Mn <sub>2</sub> O <sub>3</sub> .....	60.44	63.85	.405 } 1
Fe <sub>2</sub> O <sub>3</sub> .....	.77	0.83	.005 }
ZnO.....	33.43	35.32	.435 } 1.06
SiO <sub>2</sub> .....	1.71		
H <sub>2</sub> O—.....	2.47		
H <sub>2</sub> O+.....	1.42		
100.24		100.00	
Hausmannite,		MnO.Mn <sub>2</sub> O <sub>3</sub>	
Hetærolite,		ZnO.Mn <sub>2</sub> O <sub>3</sub>	

*Pyroxenes: Composition.*

Manganese- and zinc-bearing varieties of pyroxene are characteristic both of the granite and of the intruded rocks near the contacts at Franklin Furnace and Stirling Hill. The dis

\* State of oxidation of iron and manganese not known.

tinctions between these pyroxenes are not sharply defined. Jeffersonite, the most abundant of them, contains manganese zinc and iron in addition to lime and very little magnesium. Zinc schefferite differs in the practical absence of iron and in the increase of calcium and magnesium at expense of manganese and zinc. Schefferite, close to the last named, contains no zinc, little iron and a larger proportion of magnesium. Schefferite was found only in well-defined crystals in limestone from Stirling Hill. The analyses here given are of a very fresh jeffersonite from Parker shaft, Franklin Furnace, and of schefferite which has not been before described from this region.

1. Analysis of jeffersonite, Steiger, U. S. G. S., 1906.

2. Analysis of schefferite, Schaller, U. S. G. S., 1907.

	SiO <sub>2</sub>	CaO	MgO	MnO	ZnO	FeO	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	H <sub>2</sub> O—	H <sub>2</sub> O+	Na <sub>2</sub> O	CO <sub>2</sub>
1	49.03	19.88	5.81	7.91	7.14	8.95	0.86	4.22	0.60	0.70		
											[100.14]	
2	49.80	21.07	12.35	9.69	tr.	1.61	0.26	1.46	1.55	1.81	0.9	0.43
									[F = 0.81 = 99.98 less		.18 = +	

#### *Nasonite: Crystal Form.*

The crystal form of nasonite could not be determined by Penfield in the absence of crystals, but he concluded that it was tetragonal because of chemical analogy with ganomalite—a tetragonal mineral.

Crystals of nasonite were intrusted to the writer by Mr. Canfield, who had recognized their hexagonal character. One of them proved measurable and showed the forms  $a$  (11 $\bar{2}$ 0),  $m$  (10 $\bar{1}$ 0),  $p$  (10 $\bar{1}$ 1) and  $x$  (90 $\bar{9}$ 2), the hexagonal symmetry being well defined. The axial ratio, based on two measurements of angle  $c \wedge p = 56^\circ 40'$ , is  $a:c=1:1.3167$ .

Angle  $c \wedge x$ , calculated  $81^\circ 41'$ , measured  $81^\circ 36'$ .

The faces of  $m$  are cavernous except at the prism edges, where they are well defined and generally truncated by  $a$ . The prism rounds over into the pyramid  $p$  on most of the small crystals seen, the form  $x$  representing a plane face  $t$  in this surface on one crystal. The faces of  $p$  were dull on all except the measured crystal. This was afterwards tested qualitatively and gave the reactions of nasonite.

#### *Glaucochroite: Crystal Form.*

Terminated crystals were not present in the original specimens of glaucochroite described by Penfield, but he obtained an approximate axial ratio by measurement of the inclination of individuals in twin position.

Two terminated crystals were secured from a specimen loaned by the Foote Mineral Co. which yielded fair measurements, determining the following axial ratio and forms.

$$a : b : c = .4409 : 1 : .5808 \\ = .440 : 1 : .566 \text{ (Penfield).}$$

Forms : *a* (100), *b* (010), *m* (110), *s* (120), *x* (103), *h* (021) *e* (111), *f* (121).

Combinations : 1. *b. m. s. x.*

2. *a. b. m. s. k. e. f.*

Angles :	Calculated		Measured		
	$\phi$	$\rho$	$\phi$	$\rho$	
111	66° 12'	55 13	66 13	55 15	2 faces good
121	48 36	60 12	49 22	60 29	1 face poor
110	69 12	90 00	66 09	90 00	4 faces good
120	48 36	90 00	49 14	90 00	poor

### *Bementite: Composition, System.*

The description of bementite by Koenig was incomplete and its relations were not clear. Study of a later find of better material from the Parker shaft, Franklin Furnace, establishes its close relationship to tephroite in system and composition.

System orthorhombic, shown by three pinacoidal cleavages at right angles but unequally perfect; and by a symmetrical biaxial interference figure with small axial angle seen on plates parallel to the best cleavage.

The analysis given below agrees closely with that of Koenig, but the water is shown to be constitutional, coming off for the most part at a red heat. It leads to the formula  $H_2Mn_2(SiO_3)_4$ , with more or less replacement of manganese by iron, zinc and magnesium. This is analogous to the formula of tephroite, which may be written  $Mn_2Si_2O_{10}$ ; in bementite three molecules of manganese are replaced by constitutional water. That it is not a simple case of partial hydration is shown by the optical homogeneity of the bementite crystals.

1. Analysis of bementite, Geo. Steiger, U. S. G. S., 1906.

2. Same recalculated to 100 per cent after omitting  $Al_2O_3$ ,  $Fe_2O_3$ , and  $H_2O$ —and substituting for  $FeO$ ,  $MgO$ ,  $CaO$ , and  $ZnO$ , equivalent amounts of  $MnO$ .

3. Theory for  $H_2Mn_2(SiO_3)_4$ .

	$SiO_2$	$MnO$	$FeO$	$ZnO$	$MgO$	$CaO$	$H_2O + H_2O -$	$Al_2O_3$	$Fe_2O_3$	
1	38.36	39.22	4.94	2.93	3.35	0.62	8.01	0.60	0.96	99.70
2	37.93	53.56					8.51			100.00
3	37.18	54.53					8.29			100.00

### *Willemite: Axial Ratio, Refractive Indices.*

No accurate measurements of willemite crystals from New Jersey have been hitherto recorded. The fundamental angle employed by Dana was based on contact measurements of troostite. Other authors use the element determined by Lévy on crystals from Moresnet, on which the sole form is a rhombohedron not found on Franklin crystals. A number of measurable crystals, all from the Parker shaft, Franklin Furnace,

passed through the writer's hands and the data secured from them permit the establishment of a satisfactory axial ratio. The five measured crystals were colorless or pale green prisms terminated by the base and one or both of the rhombohedrons  $e$  (0112) and  $r$  (1011).

Angle  $c \wedge e$ , 19 readings average  $20^\circ 47'$ , limits  $20^\circ 35' - 21^\circ 04'$   
 "  $c \wedge r$ , 14 " "  $37^\circ 35'$ , "  $37^\circ 20' - 37^\circ 40'$

Whence  $a : c = 1 : 0.6612$

Lévy " =  $1 : 0.6696$

Dana " =  $1 : 0.6775$

Calculated angle,  $c \wedge e = 20^\circ 53'$

" "  $c \wedge r = 37^\circ 22'$

Refractive indices, measured on a prism  $\parallel c$ .

Sodium light,  $\omega = 1.69390$   $\epsilon = 1.72304$

Lithuim "  $\omega = 1.68897$   $\epsilon = 1.71812$

#### *Friedelite: Occurrence; Composition.*

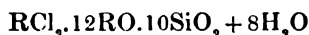
Friedelite has not been before described from America. It was identified by the writer on a single specimen from Buckwheat mine, Franklin Furnace, in the Kemble Collection, and in minute amount on specimens from the Parker shaft. The mineral occurs in scales or tabular crystals with the unit rhombohedron and base, not measurable.

The analysis, with others for comparison, follows:

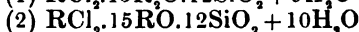
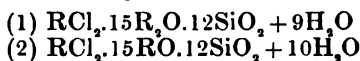
1. Friedelite, Franklin Furnace, Schaller, U. S. G. S., 1906.
2. Same recalculated to 100 per cent after removing  $H_2O$ —and substituting equivalents of  $MnO$  for  $FeO$ ,  $MgO$ ,  $ZnO$  and  $CaO$ .
3. Average of four analyses of friedelite (Dana, System and 1st Appen.) recalculated as in number 2 above.
4. Theory for  $H_2$  ( $MnCl$ )  $Mn_7$  ( $SiO_4$ )<sub>6</sub>.
5. Theory for  $H_{20}$  ( $MnCl$ )<sub>10</sub>  $Mn_{14}$   $Si_{12}O_{40}$ .
6. Theory for  $H_{10}$  ( $MnCl$ )<sub>5</sub>  $R_{11}$   $Si_{10}O_{40}$  (Zambonini).

	1	2	3	4	5	6
SiO <sub>2</sub>	34.69	34.95	34.14	34.73	34.43	34.84
MnO	48.00	53.22	54.35	54.80	54.33	53.60
Cl	3.43	3.45	3.42	3.42	3.39	4.12
H <sub>2</sub> O +	9.08	9.15	8.84	7.82	8.60	8.36
H <sub>2</sub> O —	1.94					
FeO	1.45					
MgO	.98					
ZnO	1.05					
CaO	.63					
	101.25	100.77	100.75	100.77	100.75	100.92
Less O = Cl	.77	.77	.75	.77	0.75	.92
	100.48	100.00	100.00	100.00	100.00	100.00

The Franklin friedelite agrees closely in composition with that of other localities, as shown by comparison of columns 2 and 3. Groth's formula for the mineral, used by Dana, does not well express the results of these analyses, which uniformly give a higher content of manganese or its equivalents and a lower content of chlorine than demanded by it. The formula adopted here,  $H_{10}(MnCl)_2Mn_7(SiO_3)_8$ , is satisfactory as to all constituents save water, for which it is too low. The formula  $H_{10}(MnCl)_2Mn_7Si_8O_{28}$ , obtained by adding one-half molecule of water to the latter, comes nearest to the exact equivalent of the analytical data but was rejected as not being reducible to the orthosilicate form. Zambonini\* has derived for pyrosmalite and friedelite the formula



an expression which takes no cognizance of the fact that the water in these minerals is combined. The above formulas, reduced to this form of expression, are:



This formula of Zambonini gives a composition very similar to (2) and quite as close to the analytical results except for chlorine, which is too high. It is better than (1) as to water but is no closer in regard to other constituents.

*Vesuvianite, variety Cyprine: Analysis.*

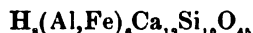
Bluish green fibrous vesuvianite corresponding in character with the Norwegian cyprine was found in 1905 in granite from the Parker shaft. The material was carefully freed from minute specks of metallic copper and had a specific gravity of 3.451. The analysis by Steiger, U. S. G. S., 1907, follows:

SiO <sub>2</sub>	36.41	PbO	trace
Al <sub>2</sub> O <sub>3</sub>	17.35	Na <sub>2</sub> O	0.44
Fe <sub>2</sub> O <sub>3</sub> }	1.86	K <sub>2</sub> O	0.50
FeO }		H <sub>2</sub> O—	0.24
MgO	1.38	H <sub>2</sub> O +	3.51
MnO	1.75	F	0.36
ZnO	1.74		
CuO	1.85		100.23
CaO	33.21	less O = F	0.17

Sum 100.06

This analysis agrees closely with that of the cyprine from Tellemarken save in the greater amount of water and less fluorine. It corresponds to the formula:

\* Zeitschr. Kryst., xxxiv, 554.



with part of the lime replaced by a number of oxides.

*Datolite: Crystal Form.*

Datolite has been known for some time from the Parker shaft, Franklin Furnace, but crystals have not hitherto been described from there. Complex crystals were found in a specimen in the Harvard Collection on which were observed a number of forms including several new to the species. In the following list new forms are marked with an asterisk :

$a$  (001)  $e$  (023)  $x$  (101)  $\gamma$  (221)  $\epsilon$  ( $\bar{1}11$ )  $f$  : (241)  $k$  : ( $\bar{2}45$ )  
 $c$  (100)  $M$  (011) \* $I$  (304)  $A$  (111)  $a$  (221)  $j$  : (243)  
 $g$  (110)  $o$  (021)  $\phi$  (102)  $\theta$  (112)  $Q$  (121) \* $d$  (263).  
 $m$  (120) \* $q$  : (701)  $\zeta$  ( $\bar{1}01$ )  $Y$  (223)  $\mu$  ( $\bar{2}11$ ) \* $k$  (475)

Symbols and letters after Goldschmidt, Winkeltabellen.

The pyramid  $d$  (263), new to datolite, is present on all the crystals with characteristic form.

*Cuspidine: Occurrence; Composition.*

The occurrence of this mineral, known hitherto solely from Vesuvius, at Franklin Furnace is established by the following analysis, for which the writer is indebted to Dr. C. H. Warren.

The material, which occurred with nasonite, was isolated by hand-picking and heavy solution and analyzed by him at the time (1899) Penfield and Warren were working on nasonite and other peculiar silicates from the Parker shaft. At the time no satisfactory interpretation of the analysis was hit upon, the identity of the mineral remained hidden, and, all the material having been used in analysis, the matter was put one side. The material analyzed consisted of glassy white crystal fragments of specific gravity between 2.965 and 2.989.

I. Analysis of cuspidine, C. H. Warren, 1899.

II. Same recast and recalculated to 100 per cent after substituting equivalents of Ca for Mn, K, and Na.

I		II		Molecular Ratio	
SiO <sub>2</sub>	32.36	Si	15.10	.539	1
CaO	61.37	Ca	44.63	1.115	2.05
MnO	0.71	F <sub>2</sub>	9.05	.238	2.189
Na <sub>2</sub> O	0.48	O	31.22	1.951	
K <sub>2</sub> O	0.27				4.06
F	9.05				
<hr/>					
104.24					
Less O = F <sub>2</sub>	3.81				
<hr/>					
100.43					

The ratio  $\text{Ca} : \text{Si} : (\text{O} + \text{F}_2) = 2 : 1 : 4$  very nearly, leading to the formula  $\text{Ca}_2\text{Si}(\text{O}, \text{F}_2)_4$ . This is the formula suggested by Dana (System, 529) for cuspidine, in which fluorine is treated as replacing oxygen. No other treatment of the analytical data gave a satisfactory ratio. It is much to be regretted that no further material remains for more complete physical determination of this interesting species.

*Humite: Crystal Form.*

Minerals of the humite group have long been known from Franklin under the name of chondrodite. They have not been analyzed nor till recently have good crystals been found. In 1906 were found orthorhombic crystals of deep orange-red and pale yellow color which yielded contact measurements accurate enough to prove the material to be humite.

Forms :  $b$  (010),  $o$ , (210),  $m$  (110),  $e_\delta$  (102),  $n_a$  (112),  $r_i$  (214).

Combinations :

1.  $b$ ,  $o$ ,  $n_a$ ,  $r_i$ .
2.  $b$ ,  $o$ ,  $e_\delta$ ,  $n_a$ ,  $r_i$ .
3.  $b$ ,  $o$ ,  $m$ ,  $e_\delta$ ,  $n_a$ ,  $r_i$ .

*Leucophœnicite: Crystal Form.*

Leucophœnicite was described by Penfield, whose material did not permit him to determine the system to which the crystals belong. From its relation in composition to the humite group he believed it to be monoclinic.

Crystals of measurable quality very kindly placed in the writer's hands by Mr. Canfield, furnished data for the determination of system and forms.

System, monoclinic:—Axial ratio :  $a : b : c = 1.1045 : 1 : 2.3155$ .  
 $\beta = 76^\circ 44'$ .

Forms :

$c$ (001)	$s$ (120)	$x$ (103)	$y$ ( $\bar{1}$ 03)	$l$ (121)	$d$ (123)
$b$ (010)	$e$ (101)	$r$ ( $\bar{1}$ 01)	$o$ (011)	$n$ ( $\bar{1}$ 21)	$h$ ( $\bar{1}$ 23)
$a$ (100)	$f$ (102)	$i$ ( $\bar{1}$ 02)	$f$ (012)	$u$ ( $\bar{1}$ 22)	$q$ ( $\bar{1}$ 24)
$m$ (110)					

The crystals are of epidote habit, elongated parallel to the  $b$ -axis, the orthodome zone deeply striated. Crystals are twinned on a face in this zone which was taken as the basal pinacoid, the two individuals frequently interpenetrating. The form series is peculiar and could not be correlated in any way

with that of any member of the humite group to which leuco-phœnicite is related chemically.

The presence at Franklin Furnace or at Stirling Hill of the following minerals, not hitherto recorded, has been established: Marcasite, millerite, pyrrhotite, aurichalcite, hydrozincite, psilomelane, göthite, albite, chlorite, ganophyllite, manganese pectolite, descloizite, anglesite and native silver.

With these additions and the omission of a number of species of the older lists which could not be verified, the number of minerals recorded for this locality becomes ninety-three.

Harvard University, October, 1909.

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## SCIENTIFIC INTELLIGENCE.

### I. CHEMISTRY AND PHYSICS.

1. *The Formation of Colloidal Solutions by the Action of Ultra-violet light upon Metals.*—It was observed by Lenard and Wolf in 1889 that certain substances, particularly metals, were resolved to dust by the action of ultra-violet light. This effect was detected both by the roughening of the surfaces and the detection of the detached particles in the adjacent layers of air. It was found that different metals gave different degrees of this action, that the electrical condition of the metallic plate exerted a pronounced influence upon the action, as did also the nature of the source of light employed. These investigators did not attempt the preparation of colloidal solutions by this means, but they observed, when experimenting with a zinc plate, that a layer of water held back the zinc dust. SVEDBERG has now made use of this phenomenon in preparing colloidal solutions of various metals in various liquids. He placed the metal, the surface of which must be freed from layers of oxide, in a shallow dish, placed the liquid upon it, and exposed it to the rays of a Heraeus' quartz-mercury arc lamp at a distance of a few centimeters. After a few minutes the liquid when examined by the ultra-microscope showed the characteristic appearance of a colloidal solution. Different metals and different liquids behaved very differently. Silver, copper, tin and lead gave colloidal solutions easily, while platinum, aluminium and cadmium showed little or no effect. The action with lead was particularly strong. When water was used this metal gave a milky liquid in five minutes, probably colloidal hydroxide, while with ethyl alcohol the same metal gave a colloidal metallic solution. Further experiments with lead and silver in water and six different organic liquids indicated that



the size of the particles is very different in the various cases, and that this depends upon the nature of the liquid employed. It was especially interesting to find that it was possible to produce solutions with particles of very small, uniform size which displayed the Brownian movements in a very lively manner. Further study of this matter, which the author is undertaking, promises to be of great interest, and he suggests that it may be of importance in explaining the mechanism of common photochemical reactions.—*Berichte*, xlii, 4377.

H. L. W.

2. *Potassium Percarbonate*.—Much uncertainty has arisen in regard to the true constitution of the product prepared in 1897 by Constam and von Hansen by the electrolysis of concentrated potassium carbonate solutions to which the percarbonate formula,  $K_2C_2O_6$ , was ascribed by the discoverers. Up to the present time this product has always been obtained in an impure condition, containing carbonate, bicarbonate and water, and since it yields hydrogen peroxide and potassium carbonate when dissolved in water, it has been possible to regard it as potassium carbonate with hydrogen peroxide of crystallization, instead of a true percarbonate. Moreover Tantar has obtained a well crystallized product by the combination of sodium carbonate and hydrogen peroxide, to which he gave the formula  $Na_2CO_3 + \frac{1}{2}H_2O_2 + H_2O$ , regarding it as a percarbonate combined with both hydrogen peroxide and water.

RIKSENFELD and REINHOLD have now succeeded in preparing the electrolytic product in a nearly pure anhydrous condition by the use of special precautions. The absence of hydrogen in this preparation proved that it was not a hydrogen peroxide addition product and analyses confirmed the formula  $K_2C_2O_6$ . They have also found a means for distinguishing between percarbonate and hydrogen peroxide in the fact that the former liberates iodine immediately from a neutral potassium iodide solution, while hydrogen peroxide acts only slowly upon such a solution. By means of this reaction they found that Tantar's product contains no percarbonate, so that its formula should be given as  $Na_2CO_3 + 1\frac{1}{2}H_2O_2$ .—*Berichte*, xlii, 4377.

H. L. W.

3. *A Practical Application of Radium*.—In connection with a research on a revision of the atomic weights of iodine and silver, BAXTER and TILLEY found it necessary to determine small quantities of water in the iodine pentoxide which they were analyzing. This water was absorbed and weighed in glass U-tubes containing phosphorus pentoxide. The usual difficulty in weighing glass apparatus, due to electrical disturbance from wiping it, was avoided here by placing in the balance a few milligrams of radium bromide of radio-activity 10·000 to dispel electrical charges. Under these conditions no difficulty was experienced in weighing the tubes within a few hundredths of a milligram, since they quickly came to constancy in the balance case and retained their weights unchanged for days at a time.—*Jour. Amer. Chem. Soc.*, xxxi, 212.

H. L. W.

4. *Volumetric Determination of Selenious Acid.*—L. MARINO has devised a method for this purpose which he prefers to those previously in use. The solution of the selenious acid is made slightly alkaline with sodium hydroxide solution, then a specially prepared alkaline permanganate solution is added gradually, until after heating to boiling a strong violet color is permanent for 4 or 5 minutes. After cooling somewhat the liquid is acidified with dilute sulphuric acid, and an oxalic solution is run in until all the manganese dioxide has dissolved. Then, finally, the excess of oxalic acid is titrated with the permanganate solution. The test-analyses given show very satisfactory results. A special method is given for the removal of nitrates in order that this method may be applied.—*Zeitschr. Anorgan. Chem.*, lxx, 32.

H. L. W.

5. *A Contract for Radium.*—It is stated on the authority of the London Times that a contract has recently been entered into between the British Metalliferous Mines (Limited) and Lord Iveagh and Sir Ernest Cassel for the supply of  $7\frac{1}{2}$  grams of pure radium bromide at the rate of four pounds per milligram (total about \$150,000). The source is pitchblende from the company's mine in Cornwall. This radium bromide is to be presented by Lord Iveagh and Sir Ernest Cassel to the Radium Institute, which will be under the direction of Sir Frederick Treves, for use in the treatment of cancer.—*Chem. News*, xci, 303. H. L. W.

6. *Absolute Measurement of High Pressure with the Amagat Manometer.*—PETER PAUL KOCH and ERNST WAGNER have described in a previous paper a method of measuring accurately high pressures which gave very satisfactory results; but in order to reach a higher degree of exactness they concluded to measure the pressures directly by a height of mercury. The tower of the Laboratory in Munich afforded a height of 25<sup>m</sup>, and they describe the arrangement of steel tubes by means of which they contained the mercury. A comparison is given of the results of the Amagat manometer, with the results obtained by direct measures, obtained from the height of the mercury column. A constant of correction is given.—*Ann. der Physik*, 1910, No. 1, pp. 31–50.

J. T.

7. *A Relation Between Absorption and Phosphorescence.*—The observations of M. G. Lecoq de Boisfaudran and M. G. Urban show that the best known phosphorescent bodies result from a *phosphorogène* in a solvent or diluent. M. L. BRÜNINGHAUS points out a very simple relation between absorption and phosphorescence. The light emanating from the *phosphorogène* molecules situated in the depths of the medium suffer absorption by the superficial layers, and the radiations observed at the surface are only those for which the *phosphorogène* is relatively transparent.—*Comptes Rendus*, Dec. 13, 1909, pp. 1124–1129.

J. T.

8. *Mass of Moving Electrons.*—The new theories of electrons are concerned with hypotheses of change of mass with velocity.

AM. JOUR. SCI.—FOURTH SERIES, VOL. XXIX, No. 170.—FEBRUARY, 1910.

Abraham supposes electrons unchanged by velocity, while the Lorentz-Einstein theory is based upon the relativity principle. E. HUPKA in his investigation endeavors to decide which theory is the most probable. The article is interesting principally from the view of technic: for the author describes minutely the method by means of which he excited electron streams in high vacua. Although he did not attain to the velocity of the  $\beta$  ray, he succeeded in producing rays of great homogeneity, suitable for measurement. The vacua were produced by liquid air and the use of charcoal, and he used potentials as high as 90,000 volts. The paper contains many tables and plotted charts, giving comparisons of results on the Abraham or solid sphere theory and the Lorentz-Einstein relativity principle. The measurements agree better with the latter theory than with the sphere theory of Abraham.—*Ann. der Physik*, 1910, No. 1, pp. 169–204.

J. T.

9. *Hertz's Photoelectric Effect*.—M. EUGÈNE BLOCH criticizes the conclusion that this effect coincides in greatness with the Volta series, the metals, more photoelectric, being the more electropositive, and believes that the order can be reversed when one passes from one wave length to another.—*Comptes Rendus*, Dec. 13, 1909, p. 1110.

J. T.

10. *Influence of Thunder on Size of Raindrops*.—V. J. LAINE has studied the changes in rainbows which apparently follow peals of thunder. He describes as follows a typical case: Between six o'clock and five o'clock in the evening he observed in the East a rainbow accompanied by a secondary bow. During thunder the colors of both bows trembled to such a degree that the color limits and the edges of the bows were entirely weakened, and one observed very quick vibrations over the entire rainbow. This occurred with each peal of thunder. The change in color Laine attributes to changes in size of raindrops. The size before peals of thunder was under  $0.1^{\text{mm}}$ , and during the thunder it increased to  $0.5^{\text{mm}}$  and to  $1^{\text{mm}}$ . The author attributes the change to the acoustical vibration of the thunder.—*Physikal. Zeitschrift*, Dec. 1, 1909, pp. 965–967.

J. T.

11. *Conduction of Electricity through Gases and Radioactivity*; by R. K. McCLUNG. Pp xvi + 245. Philadelphia, 1909. (P. Blakiston's Son & Co.)—This is a "text-book with experiments" designed to introduce college classes to the fascinating and important subjects indicated by the title. There has been so great a development during the past twelve years in our knowledge of the ionization of gases and the properties of the newly discovered radiations that ample material exists for an interesting and instructive course for students. The present book is the first to be written with this end in view, and it seems well adapted to the purpose. The descriptive portions though very concise are fairly satisfactory and many useful directions are given for performing experiments in this field.

H. A. B.

12. *Die Strahlen der positiven Elektrizität*; von E. GEHRCKE. Pp. xi + 124. Leipzig, 1909. (S. Hirzel.)—This is an excellent and timely account of a class of radiations which have of late years come to be of great importance in physics. The rays which consist of positively charged particles include the canal rays discovered many years ago by Goldstein, certain other rays which are observed in ordinary vacuum tubes, the  $\alpha$ -rays from radioactive substances and the "anode rays" (recently discovered by Gehrcke and Reichenheim), which are given out by anodes consisting of the salts of various metals. The properties of all these rays and their accompanying phenomena are described in detail, and the book forms a very useful collection of data upon an important subject.

H. A. B.

## II. GEOLOGY AND NATURAL HISTORY.

1. *United States Geological Survey, Thirtieth Annual Report, 1908-1909, of the Director, GEORGE O. SMITH*. Pp. 128, with two plates.—This report contains a statement of the work done by the various divisions of the Survey during the fiscal year ending June 30, 1909. Besides the progress in geologic investigations and topographic mapping, for which the Survey was initially organized, the special lines of work which Congress has delegated to it are worthy of note. The classification of public lands has been carried forward with great activity, resulting in a proper valuation of land according to the use for which it is most valuable. As a consequence the government is deriving a revenue from the sale or lease of said lands many times greater than the cost of the surveys. Fraudulent entries are made more difficult and monopolistic control is prevented, but immediate utilization is fostered; the present system resulting in the greatest good to the nation at large.

The division of mine accidents has been organized within the year, studies have been carried on in Europe and in this country and already large results begin to show toward the prevention of the destruction of both human life and mineral resources.

The technologic branch by its investigations of materials used in government contracts has, during the year, guarded the expenditure of tens of millions of dollars and saved millions to the government.

Because these additions to the work of the Survey are so immediately important and popularly recognized as of great value, conscious effort should be maintained to prevent their encroachment upon the equally valuable purely scientific work upon which such developments ultimately rest. That Congress does not fully appreciate this broader view is shown by the fact that the Survey was only granted \$100,000 for stream measurements, whereas \$250,000 was appropriated for testing fuels. For topo-

graphic surveys \$300,000 was appropriated, for geologic surveys \$200,000, as during the previous year. The entire appropriation for the year was \$1,590,680. J. B.

2. *Fifth Biennial Report. State Geological Survey of North Dakota*; A. G. LEONARD, State Geologist. Pp. 278, plates xxx. Bismarck, North Dakota.—The purposes of the reports of the survey are educational in the teaching of physical geography and elementary geology, and developmental of the economic resources of the state. In this volume, besides the administrative report, there are papers on the geology of southwestern North Dakota with special reference to the coal, by A. G. Leonard; the geology of northeastern North Dakota with special reference to cement materials, by John G. Barry and V. J. Melsted; the geological history of North Dakota, by A. G. Leonard; the Bottineau gas field, by John G. Barry, and a paper on good roads and road materials, by W. H. Clark. The papers in general meet well the purposes for which they are planned and the survey by such a report demonstrates its value to the state. The paper on the geological history of North Dakota could, however, have been improved in a number of particulars.

It was prepared for the use of schools and the general reader, yet there is no statement in it of the fundamental conception that geologic time embraces tens of millions of years. Yet without such discussion the general reader is apt to preserve the inherited notion that time is antediluvian and postdiluvian and the whole embraced in some thousands of years. This, however, is a minor point in comparison with definite errors retained from an earlier period in geology. For example, it is sweepingly stated that "granites are examples of Archean rocks." Whereas they are now known to occur as massive intrusive rocks of any age up to middle Tertiary. Further, it is stated "that the oldest part of the continent, that which was the first to be raised above the sea, was a U-shaped land mass, the two arms of the U enclosing Hudson Bay. At the beginning of the Paleozoic Era by far the greater part of our continent, with the exception of the above land, was beneath the sea." This statement may be compared with Walcott's well-founded conclusions, published in 1891, that the area of the pre-Cambrian Algonkian continent was larger than at any succeeding period until the Mesozoic, and that the Cambrian sea did not begin to invade the great interior continental area until late Middle Cambrian time. It is true that these and other important conceptions have not been properly emphasized in many text-books, but that cannot be regarded as good reason for their further perpetuation. Their importance in geologic theory is, furthermore, such as to warrant calling attention to their occurrence in this report. The idea, however, of publishing in state reports popular expositions of geologic structure and history, as is here done, is a most valuable one from the educational point of view, and one which state surveys have largely neglected. J. B.

3. *The Figure of the Earth and Isostasy from Measurements in the United States*; by JOHN F. HAYFORD, Inspector of Geodetic Work, and Chief, Computing Division Coast and Geodetic Survey. Pp. 178, plates and figures 17. Washington, 1909.— This report is one of great interest to geodesists and geologists, for though the principal conclusions have been previously published by Hayford, this is the first appearance of the complete work. The author points out that earlier computations upon the elements of the spheroid have regarded the deflections of the vertical as accidental errors, an assumption which is evidently untrue. By considering them as due to the known irregularities in topography largely counterbalanced by the unknown irregularities in subsurface densities, a solution is reached giving the character of the latter, and by thus allowing for constant errors attaining more correct and larger values for the dimensions of the spheroid. By assuming in the solution the existence of certain deficiencies of mass underlying elevated tracts, the weight of the new determination of the terrestrial dimensions becomes 1.7 times that derived otherwise. This may be taken as a mathematical demonstration of isostasy. Hayford furthermore finds that isostatic adjustment is so nearly complete that the deflections of the vertical average are less than a tenth of what they would be if due to topographic irregularities alone and the stress differences in the crust are not more than one-twentieth what they would be if isostasy did not prevail. Consequently the United States is not maintained in its position above sea level by terrestrial rigidity but is in the main buoyed up, floated, in each of its parts, because it is composed of material of deficient but irregular density. The solution further shows that the flotation is not due to a lighter crust resting upon a fluid and denser substratum and that the isostatic compensation is approximately satisfied within a hundred miles of the surface. This report brings forth the results of a monumental labor and its author and the organization which he represents are to be congratulated upon its completion. The results will be most interesting if gravity determinations are now made in order to throw further light upon the variations in subsurface densities extending to the depth at which isostatic compensation becomes complete.

The reviewer would point out that the conclusion, that the various physiographic provinces are now so closely compensated that the unbalanced stresses in the earth are not more than a twentieth as great as they would be if isostatic adjustment did not prevail, is seemingly at variance with the geological evidence that the crust is able to remain unwarped during long periods of time, permitting the wide development of base-leveled surfaces. The reconciliation of these two well-founded conclusions of modern geology is one of the larger problems awaiting solution in the future. Although, as Willis has suggested, the present epoch may be one of unusually complete isostatic adjustment, how comes it that if so complete at present, at other times the crust could for so long have resisted the stresses due to widespread erosion?

J. B.

4. *Geological Survey, Cape of Good Hope*; by A. W. ROGERS, Director; 13th Annual Report, Cape Town, 1908.—The 1908 Report of the Geological Commission contains the following papers: (1) Report on the Geology of parts of Prieska, Hay, Britstown, Carnarvon and Victoria West, by A. W. Rogers and A. L. du Toit; pp. 9-109, figs. 13; (2) The kimberlite and allied pipes and fissures in Prieska, Britstown, Victoria West and Carnarvon, by A. L. du Toit; pp. 111-127, 3 figs.; (3) Notes on a journey to Knysna, by A. W. Rogers; pp. 129-134, 1 plan.; (4) The Tygerberg anticline in Prince Albert, by A. W. Rogers; pp. 135-139. Field work in Prieska and adjoining regions included a study of areas previously mapped, with the result that errors were found to have been made in the determination of structural and stratigraphic relations. This present report, therefore, replaces in large part the report for 1899. (This Journal, xiii, 413.) New occurrences of Dwyka beds are described and petrographic studies have been made of a number of igneous and metamorphic rocks including an unusually large variety of granulites, the origin of which is in doubt. An interesting economic feature is the fact that the water supply is found in decomposed dikes of kimberlite, etc., rather than in the shales and other sedimentaries.

H. E. G.

5. *The Devonian fauna of the Ouray limestone*; by E. M. KINDLE. Bull. 391, U. S. Geol. Survey, 1909; pp. 60, plates 10.—This Upper Devonian fauna characterized by *Plethorhynchia endlichii* and *Spirifer* cf. *whitneyi* is now known to extend from southern New Mexico to the north line of Colorado. It is composed of 40 species, most of which are restricted to this biota. The strikingly new element is a brachiopod related to *Syringothyris*, for which is here proposed the new generic name *Syringospira*.

The author does well in removing for western faunas the name *Spirifer disjunctus*, but he should have gone a step farther and renamed the so-called *S. whitneyi*, as these Colorado shells are not identical with the typical Iowa individuals. The reviewer has seen the Ouray species also in the Three Forks of Montana and in British Columbia north of the Canadian Pacific Railway. c. s.

6. *Lower Paleozoic Hyolithidae from Girvan*; by F. R. COWPER REED. Trans. Royal Soc. Edinburgh, 47, 1909; pp. 203-222, pls. 3.—From the Ordovician and Silurian beds of the Girvan district the author describes 10 new species of Hyolithes, 4 Orthotheca, 2 Ceratotheca, and 5 Pterotheca. c. s.

7. *Die asiatischen Fusulinen. Die Fusulinen von Darwas*; von GÜNTER DYHRENFURTH. Paläontographica, Band 56, 1909, pp. 137-176, pls. 13-16.—In this work, which is a continuation of Ernst Schellwien's contemplated Monographie der Fusulinen, are described with great care six forms of Fusulina illustrated by many microphotographs. The geologic occurrence is also fully given. c. s.

8. *Paläozoische Seesterne Deutschlands. I. Die echten Asteriden der rheinischen Grauwacke*; FRIEDRICH SCHÖNDORF, *Paläontographica*, 56, 1909, pp. 38-112, pls. 6-11.—Here are described in detail 12 species of Lower Devonian starfishes of the family Xenasteridæ. These are grouped in the genera *Xenaster* (4 species), *Spaniaster* (1), *Agalmaster* n. gen. (3), *Rhenaster* n. gen. (1), *Trimeraster* n. gen. (1), *Eifelaster* n. gen. (1), and *Asterias*. The drawings are somewhat diagrammatic but illustrate the characters far better than would photographs.

In all the genera the ambulacra are directly opposite one another and do not alternate. The ambulacra and adambulacra are also opposite each other. The mouth opening is bounded by 5 pairs of mouth plates and 5 pairs of slightly modified ambulacra. No ocular plates are preserved, according to the author; the reviewer has seen none in these old starfishes before the time of the Lower Carboniferous. c. s.

9. *La Vallée de Binn (Valais). Étude géographique, géologique, minéralogique et pittoresque*; par LÉON DESBUISSONS. Pp. viii, 324; 51 illustrations, etc. Lausanne, 1909 (G. Bridel & Co.).—This is a popular work on a mineralogical locality which occupies a unique position in the interest of the occurrence and the almost inexhaustible variety of new and rare species which it has afforded. These facts are briefly summarized here, and many illustrations give an admirable idea of the scenery of the valley.

10. *Catalogue of the Fossil Bryozoa in the Department of Geology, British Museum of Natural History*. The Cretaceous Bryozoa, Volume II; by J. W. GREGORY. Pp. xlviii, 346, 9 plates, 75 figures.—The first volume of this catalogue was published in 1899 and the appearance of the present volume has been delayed in consequence of the retirement of the author from the staff of the British Museum. In the years which have intervened a large amount of material has been added to the collections of the Museum, so that the whole work has been expanded and when complete will embrace a third concluding volume. It is expected that this will be shortly prepared by Mr. W. D. Lang, who succeeded Dr. Gregory as Assistant in charge of this section of the Museum.

11. *A Hand-List of the Genera and Species of Birds [Nomenclator Avium tum Fossilium tum Viventium]*; by R. BOWDLER SHARPE. Volume V. Pp. xx, 694.—This volume of the British Museum Handlist of Birds deserves to be especially noted, since it completes a large and most important labor begun in 1898. The author and those who have worked with him deserve the congratulations of zoologists for what they have done in this way to advance the study of ornithology.

12. *Physiologische Pflanzen-Anatomie*; von Dr. G. HABERLANDT. Pp. xviii, 650. Vierte Auflage. Leipzig, 1909 (Wilhelm Engelmann).—This is the fourth and enlarged revision of a very important work. A quarter of a century has passed since Professor Haberlandt, then as now at Graz, published the first



edition. The treatise was recognized from the outset as opening up fresh fields of research on the borders between three allied departments of Botany. The relations which exist between form, function, and origin are sometimes exceedingly obscure, and this obscurity was deepened in many instances by the neglect of some gross morphologists to investigate the minute anatomy of the organs in question. To Schwendener and Haberlandt is due a large part of the credit for stimulating observers to enter upon this middle ground in the right way. The present volume by Haberlandt is in many respects a great improvement upon the previous editions, since it enters more boldly upon the field of œcology and brings up some of the very attractive questions in the domain of what we may term applied physiology. It is truly surprising to notice the small number of changes in the statement of facts which the author has been compelled to make in the period of twenty-five years. The extreme caution which characterized the early edition has borne good fruit in the later ones, since there have been practically no mistakes to recall. The treatise in its enlarged form is of great value to morphologists, anatomists, and œcologists, and, in a general way, to systematists, as well.

The publisher has wisely reprinted as a separate, the pages devoted to the irritable organs of plants, since the subject of sensitiveness is attracting at the present time a good deal of attention. A few physiologists will not agree with some of Haberlandt's conclusions, but even they must admit his fairness and clearness.

G. L. G.

### III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Report of the Secretary of the Smithsonian Institution*, Dr. CHARLES D. WALCOTT, *for the year ending June 30, 1909*. Pp. 95.—The annual report of the Secretary of the Smithsonian Institution for the year ending June, 1909, has recently appeared. It gives the usual interesting summary in regard to the activity of the Institution in its varied functions. Dr. Walcott draws attention to the fact that in the estimates for the present year there is an increase of \$10,000 for the Bureau of Ethnology, to be used in connection with researches among the tribes of the Middle West and also in Hawaii and Samoa. A larger appropriation is also called for to carry on the work of the Astrophysical Observatory, for the Zoological Park, and particularly for the new building of the National Museum, which is now nearing completion. In regard to the latter it is stated that the entire stone work of the outer walls is completed, as also the roofs and skylights, and much progress has been made in the interior, that it was expected that some of the halls and work-rooms would be ready for use early in the autumn (1909). The International Tuberculosis Congress, in the autumn of 1908, utilized

for its meetings and exhibitions a large part of the first and second floors. A full statement in regard to the National Museum as a whole is given by Dr. Rathbun in the volume noted below.

A brief summary is given of the first accessions to the Museum from the Roosevelt expedition in Africa. The results have been even more important than anticipated, including many excellent specimens, particularly of the skins of the larger mammals. Special funds were provided by friends of the Institution to pay for the outfit and expenses of the naturalists who accompanied Col. Roosevelt, while his own expenses, with those of his son, have been met by himself. Mr. W. W. McMillan of Juja farm near Nairobi, East Africa, has presented an exceptionally fine collection of living African animals.

Of other scientific work carried out under the auspices of the Institution may be mentioned the continued explorations by the Secretary, Dr. Walcott, in Montana and the Canadian Rockies, having as their object the study of Cambrian geology and paleontology. Professor J. P. Iddings is now carrying on researches on a Smithsonian grant in Japan, Eastern China, and Java. Miss Alice Eastwood, also as the result of a grant, has re-collected the botanical species from the region of Santa Barbara secured by Thomas Nuttall in 1836. Under the Hodgkins fund several investigations have been prosecuted. The statements in regard to the Library, the Gallery of Art, the Zoological Park, etc., are all interesting, but cannot be summarized here. As usual, Mr. C. G. Abbott, director of the Astrophysical Observatory, gives a summary of the work carried on under his direction at Washington, at Mt. Wilson, and on Mt. Whitney.

2. *Annual Report of the Board of Regents of the Smithsonian Institution, showing the Operations, Expenditures, and Condition of the Institution for the Year ending June 30, 1908.* Pp. x, 801, with 23 plates, 25 figures, and 4 charts.—The Secretary's Report, which forms the opening portion of this volume, was noticed a year since (see vol. xxvii, p. 196). The general Appendix (pp. 113–801) contains as usual a large series of papers on scientific subjects, covering many lines of scientific activity and discovery. No more well-selected and useful presentation of recent scientific memoirs, in a form to interest the intelligent public, can be found in a single volume. The opening paper is devoted to aeronautics and is profusely illustrated; aviation in France and wireless telephony follows, then phototelegraphy, and the gramophone; while on the Natural History side we find reproduced (from this Journal, xxv, 169) the important paper by Dr. Lull on the Evolution of the Elephant, with another on Angler Fishes by Dr. Gill. The volume closes with several biographical papers.

Recent publications from the Smithsonian Institution are noted in the following list:

Report on the Progress and Condition of the U. S. National Museum for the year ending June 30, 1909. Pp. 141.—This is a full and very interesting account of the Museum, its buildings,



4. *The Evolution of Worlds*; by PERCIVAL LOWELL. Pp. xiii, 262. New York (The Macmillan Co.).—This book is a revised edition of lectures delivered in February and March, 1909, before the Massachusetts Institute of Technology, in which institution the author is non-resident professor of astronomy. The lectures present the most recent facts and speculations regarding the past and future of the Solar system, illumined by the play of the author's active imagination and colored by an astonishing vividness of language. We do not remember to have met in any of Dr. Lowell's previous essays any such freedom in the use of English. Some of the theories which he explains are startling, but the language in which they are set forth is much more so. If we all permitted ourselves such liberties with our mother tongue it would speedily descend to a chaos and darkness such as Dr. Lowell predicts for the solar system itself.

We quote at random from the first few pages.

"Unimpressing our senses," "grandiose vicissitudes spectrally revealed," "stars cuticle," "ambidextrous impartiality of space," "The culmination of Coalition"—"the acme of accretion."

But such mishandling of language, though it irritates the reader and mars his enjoyment, does not vitiate the logic or destroy the substance of the book.

The first two chapters, entitled "Birth of a Solar System," and "Evidences of the Initial Catastrophy," will excite most interest. The author considers that the initial stage of our solar system, or rather the beginning of the cycle of change through which it is now passing, was that of a spiral nebula. From this the present order arose and to it in some distant age and region it may again return, to repeat the cycle indefinitely. Such an enormous program, which explains everything but the origin of matter and provides for its eternal activity, satisfies the mind and makes us wishful that it may be true.

Space forbids a discussion of it further than to say that the spiral form in a nebula is held to be due to action from without rather than from within, in fact to a tidal disruption caused by the passage of a large body close to the previously quiescent mass. Thus an old and worn out sun may be torn up within a few days into a meteoric nebula, heated by collisions of its fragments and developing under gravity into a planetary system.

W. B.

5. *Hyperbolic Functions*, prepared by GEORGE F. BECKER and C. E. VAN ORSTRAND. Pp. li, 321. Smithsonian Mathematical Tables, No. 1871. Washington, 1909.—In the systematic study of mathematics hyperbolic functions do not receive the attention which their practical importance as a tool of investigation warrants. Invented or first employed by Mercator in the development of his system of projection, on which to this day all deep sea navigation depends, they have come to play an important part in many branches of applied mathematics. Thus in physics whenever an active entity is extinguished or absorbed (e. g. light, velocity, radio-activity) the decay is represented by some form of

hyperbolic function. Mechanical strains also are most simply expressed in this form. Hence the study of geological deformations always requires the use of these functions; and it is for this reason that the overseers of the U. S. Geological Survey, Messrs. Becker and Van Orstrand, have prepared this most complete and scholarly treatise.

The book has a two-fold value. The tables, eight in number, furnish everything that a worker with hyperbolic functions can need, and they are preceded by an admirable exposition of the theory of hyperbolic function. The subject is developed both from an analytic and independently from a geometrical basis and the relation to elliptic functions is described and also the connection with the geometry of the pseudo sphere. An historical sketch adds greatly to the breadth of view of the subject and fifteen pages are given to formulas which the writers designate as "those most likely to be needed by computers."

This description should make it evident that the book furnishes the most satisfactory treatise on this subject that has hitherto been published.

W. B.

6. *Robbins's Plane Trigonometry*; by EDWARD R. ROBBINS. 8vo, pp. xiii, 153. New York (American Book Company).—A book well adapted for the secondary school course. It represents the experience of a mature and careful teacher whose first object is to get the essentials of the subject into the head of the average boy as quickly and firmly as possible. The learner is introduced to the solution of trigonometric equations sooner than usual, in fact in the first chapter, but the treatment of identities is postponed until quite late for the reason that the author aims to give his followers strength and courage for the assault of this formidable enemy of the weak trigonometrist. The distinction between an identity and an equation, however, is not explicitly stated.

W. B.

7. *Experimental Dairy Bacteriology*; by H. L. RUSSELL and E. G. HASTINGS. 147 pages; illustrated. Boston 1909 (Ginn and Co.).—The purpose of this book is to present an elementary course in general dairy bacteriology. Though brief and somewhat limited in its scope, it is complete in itself. The sources of milk contamination, the biological changes that take place in milk, with methods of identifying milk bacteria, the preservation of milk, butter-making, cheese, and milk as a vehicle of disease, are some of the important topics discussed. A thorough mastery of the book should enable the student to pursue intelligently more advanced work in connection with the problems of dairy bacteriology or dairy manufactures.

L. F. R.

8. *Bref och Skrifvelser af och till Carl von Linné*; af TH. M. FRIES. Pp. iv, 342. Stockholm, 1909.—This third part of the first volume of the correspondence of Linnaeus contains letters Nos. 459 to 573; they are arranged alphabetically, according to the names of the recipient or writer, from A to B. This important publication is being carried on under the auspices of the University of Upsala, and the librarian of the University asks that any persons possessing letters of Linnaeus communicate with him on the subject.

## New Circulars.

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THE

# AMERICAN JOURNAL OF SCIENCE

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ART. XIV.—*The Armor of Stegosaurus*; by RICHARD S.  
LULL.

[Contributions from the Paleontological Laboratory of Yale University.]

- I. Introductory.
- II. Character of armor.
- III. Morphology of the plates.
- IV. Position of the armor.

## I. INTRODUCTORY.

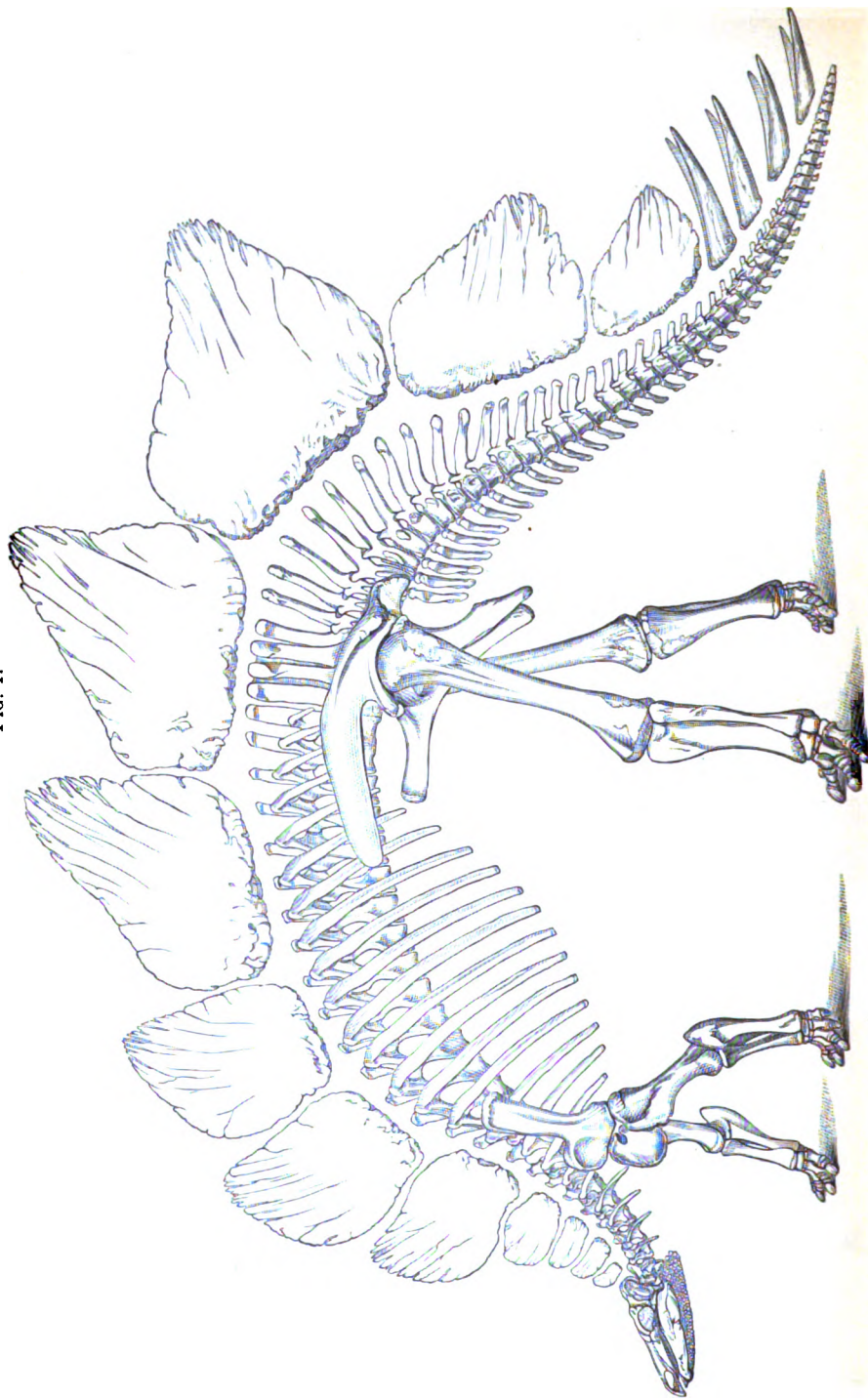
THE American genus *Stegosaurus*, first made known to science by Professor Marsh, includes the most bizarre and grotesque of armored dinosaurs; a group apparently quite apart from the glyptodon-like Ankylosauridæ with heavy mail developed over the entire body, for in *Stegosaurus* the striking armament was confined to certain regions and, so far as our knowledge goes, but little developed elsewhere.

*Stegosaurus*, while belonging to the Morrison, the beginning of the Lower Cretaceous (Lull, this Journal, vol. xxix, p. 15), was highly specialized and evidently represented a senile race, and was, as Beecher has shown with other spinescent forms, on the verge of extinction, for it shortly disappears entirely from our records.

## II. CHARACTER OF ARMOR.

The known armor of *Stegosaurus* includes five types of structures, all dermal in origin, of which the first are the small, rounded ossicles (gular plates) found *in situ* beneath the skull. These form a continuous, pavement-like investiture protecting the throat (fig. 1) and doubtless extending over a considerable portion of the body as well, though not elsewhere preserved, for it is unreasonable to suppose that an armored reptile would have any portion of the skin bereft of scutes or scales of some sort. These throat ossicles increase in size as one goes back-

FIG. 1.

FIG. 1. Restoration of *Stegosaurus ungulatus*. After Marsh. 1/30 natural size.

ward from the apex of the jaw, the largest of them being not less than 25<sup>mm</sup> in diameter.

The dorsal armor consists in turn of four distinct shapes, two apparently defensive and two offensive, with a marked differentiation in form as well as in function. Of these the first (fig. 2) are more or less oval, with a base divided longitudinally

FIG. 2.

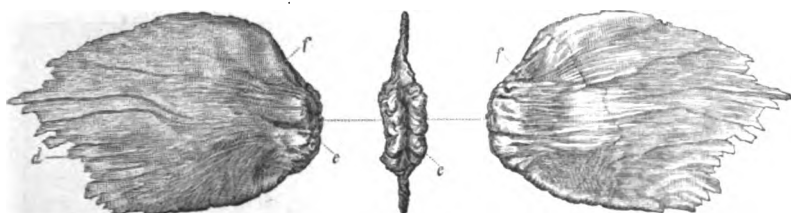


FIG. 2. Cervical plate of *Stegosaurus unguatus*. After Marsh. 1/12 natural size. *a*, side view; *b*, inferior view of base; *c*, opposite side; *d*, thin margin; *e*, rugous bases; *f* and *f'*, surface marked by vascular grooves.

by a deep cleft so as to be distinctly bifid and of very short fore and aft extent compared with the expanse of the plate. These plates show a very rapid increase in size, though the largest of them in *Stegosaurus unguatus* is only about half the height and one-third the antero-posterior diameter of the largest of the next type. These bifid based plates seem to have been borne on the neck, the largest oval one here figured (fig. 2) being near the point of junction between the neck and the trunk.

The second type are the large, thin, rectangular or somewhat triangular plates with a thick base but without the median longitudinal cleft. They doubtless stood in pairs along the trunk region and upon the proximal portion of the tail (fig. 3).

FIG. 3.

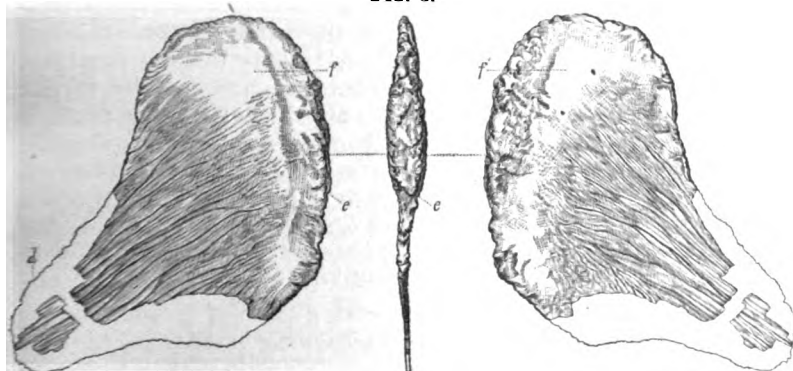


FIG. 3. Dorsal plate of *Stegosaurus unguatus*. After Marsh. 1/12 natural size. *a*, right side; *b*, thick basal margin; *c*, left side; other letters as in fig. 2.

*Stegosaurus ungulatus* as represented by the specimen (Cat. No. 1853) now being mounted at Yale was apparently the best endowed with offensive weapons of any of its relatives, for there are associated with the one skeleton no fewer than four pairs of spines and three odd, sharp-edged, spine-like plates, one of which is so much larger than the other two that it seems to imply that at least one intervening size is missing.

The spine-like plates are characterized by a very oblique, flat base, by sharp edges fore and aft and, like the others, by the impression of blood-vessels over the side expanse (fig. 4). In

FIG. 4.

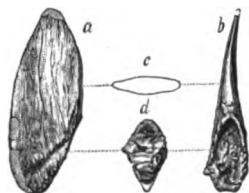


FIG. 5.

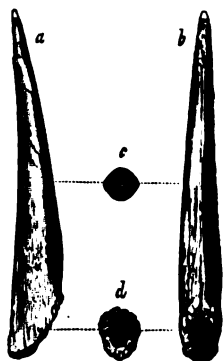


FIG. 4. Caudal spine-plate of *Stegosaurus ungulatus*. After Marsh. 1/12 natural size. *a*, side view; *b*, posterior view; *c*, section; *d*, inferior view of base.

FIG. 5. Caudal spine of *Stegosaurus ungulatus*. After Marsh. 1/12 natural size. *a*, side view; *b*, dorsal view; *c*, section; *d*, inferior view of base.

common with the dorsal plates they give evidence of having been deeply imbedded in the integument and underlying connective tissue, but, unlike the latter, they show a better surface for the attachment of muscles to give rigidity to their position.

Of the caudal spines (fig. 5) the anterior ones are the larger and more deeply embedded, being lodged in a thicker portion of the tail, and in common with all of the plates give evidence of having been ensheathed with a close-fitting integument, probably of a horny character as in the modern horned toads (*Phrynosoma*) and in *Moloch horridus*.

### III. MORPHOLOGY OF THE PLATES.

Upon comparing a given plate with a scute of a crocodile, or that of such a dinosaur as *Ankylosaurus* or *Stegopelta*, it at once becomes apparent that the great expanse of the first represents merely an enormous hypertrophy of the median ridge

or carina of the latter. This expanse is practically alike on both sides, with blood-vessel impressions and no indication that either one side or the other was in contact with the creature's

FIG. 6.



FIG. 6. Dermal plate of *Ankylosaurus*. Figured by Marsh as that of *Triceratops* and showing the median carina.  $1/8$  natural size.

flesh. On the other hand, the base, the morphological equivalent of the body of the scute in crocodile or *Ankylosaur*, is always somewhat asymmetrical even when divided into two portions by the longitudinal cleft of those of the cervical region. This base in the great dorsal plates particularly is extremely rugous, implying either a heavy pad of cartilage or a very thick connective tissue between the plate and its underlying skeletal support. There is in no instance any indication of a true articulation with the subjacent bones.

#### IV. POSITION OF THE ARMOR.

The position of the armor plates has given rise to an animated discussion as to whether they were in one row or two, opposite or alternating, erect or procumbent. The evidence seems to point to a double row of paired, erect plates, though toward the end of the tail the aggressive series evidently stood out at a decided angle from the perpendicular. It is quite possible that they were provided with an erectile musculature to give them greater rigidity especially in time of use, as is the case with the nasal horn of the rhinoceros. This seems to have been particularly true of the tail.

Professor Marsh (this Journal, xxxiv, 1887, p. 415), who first described and figured the dermal armor of *Stegosaurus*, says: "The upper portion of the neck, back of the skull, was protected by plates *arranged in pairs* [italics mine] on either side. These plates increased in size farther back and thus the trunk was shielded from injury. From the pelvic region backward, a series of huge plates stood upright along the median line, gradually diminishing in size to about the middle of the tail."

In his restoration of *Stegosaurus* (fig. 1), first published in 1891, however, Marsh places the entire series of plates in a single row along the mid-line of neck, back, and tail, although the caudal spines are represented as paired.

Evidence for pairing of the entire series is shown in two specimens preserved in the U. S. National Museum, in one of which the plates alone are represented while in the other they are actually in association with the underlying bones. These plates if placed consecutively would measure twice the length of the neck and back, the proportion being 16 to 8 feet. This evidence, together with the fact that each individual plate as shown above is in itself not symmetrical, indicates that the plates were not median but lateral structures and were arranged in at least two rows.

The first restoration showing the plates in two rows is given in a drawing made by Charles R. Knight under the direction of F. A. Lucas and published by the latter first in his book "Animals of the Past," New York, 1901, fig. 24, and again in the Smithsonian Report for 1901, plate iv. Later, under Mr. Lucas's direction, a model was made by Mr. Knight in which the number of caudal spines was reduced to two pairs and the plates were placed in such a way as to alternate along the back. The reasons given for this arrangement were two-fold: first, that the plates did actually alternate as they lay embedded in the rock, and second, that no two of them were precisely similar in exact shape or dimensions. Against the argument that no known reptile has alternating dermal elements was urged the apparent fact that this did not render it an impossibility in *Stegosaurus*. It seems to me, however, that the position of the plates in the rock is hardly conclusive, for the series of one side might easily have shifted forward or backward slightly during maceration or in the subsequent movement of the rocks, as an oblique crushing of fossil bones is a very familiar phenomenon.

The slight disparity of size and shape in the two plates of a pair is not surprising when one considers that the entire hypertrophy of the plate is in a sense abnormal and is comparable to the growth of the antlers of deer of which those borne by an individual are rarely if ever precisely similar in size, weight, form, or even in number of points. I should consider a *precise matching* of the stegosaur plates remarkable rather than the reverse. The fact that in no other reptile the lateral dermal elements alternate seems too weighty an argument to be lightly dismissed.

The evidence in favor of an erect rather than a procumbent or imbricating position is the morphology of the plate itself, as described above, and the fact that in the crocodile and gavial one can witness the actual hypertrophy of the median keel in the two rows of scutes, which finally merge into one along the mid-dorsal line of the distal half of the tail. The elevation of the keel becomes more and more pronounced beginning with

FIG. 7.

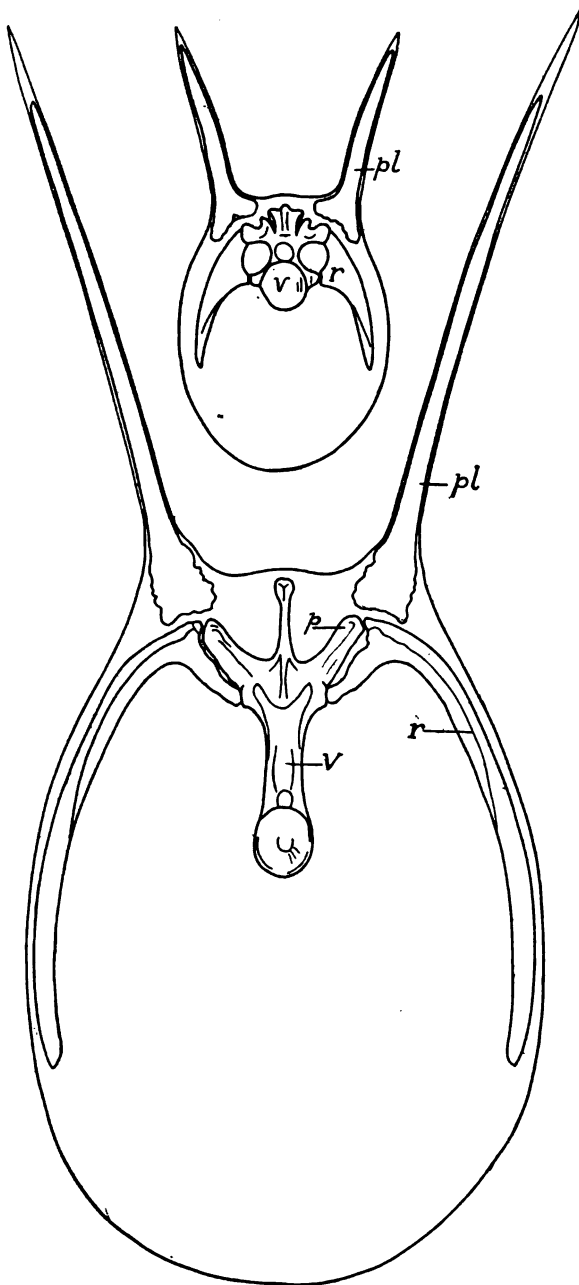


FIG. 8

FIG. 7. Section of neck of *Stegosaurus unguatus*. *pl*, plate; *r*, rib; *v*, vertebra.

FIG. 8. Section of the trunk of *Stegosaurus unguatus*. *p*, transverse process; other letters as in fig. 7.



the second quarter of the tail, reaching its maximum where the two rows merge into one and finally dwindling again toward the tip.

In the specimen of *Stegosaurus stenops*, No. 4934 of the National Museum, the last three plates, those over the sacral region, lie as though they had fallen to the right, the anterior ones to the left, a thing manifestly impossible in plates naturally procumbent on either side.

FIG. 9.

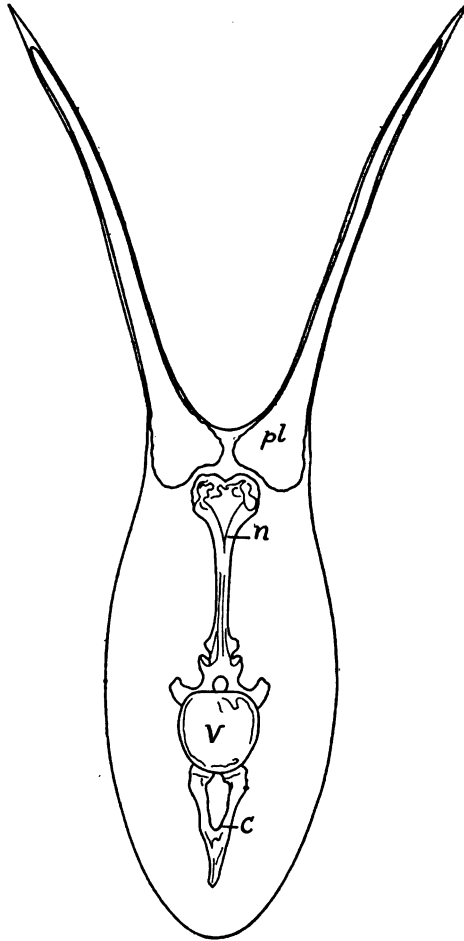


FIG. 9. Section of the proximal part of the tail of *Stegosaurus unguulatus*. c, chevron; n, neural process; other letters as in fig. 7.

FIG. 10.

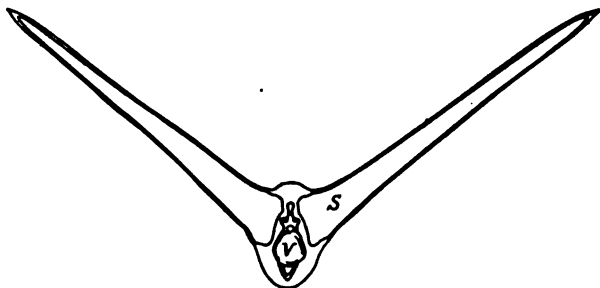


FIG. 10. Section of the distal portion of the tail through the spines. s, caudal spine; other letters as in fig. 7.

The four sections of *Stegosaurus* which I present will show the relationship of the plates to the underlying skeletal elements. The first section (fig. 7), that through the neck, shows the plates with bifid base astride the transverse process of the vertebra, and the second, that through the trunk (fig. 8), the immense broad-based plates borne over the transverse process and ribs. A beautiful mechanical device is shown in that the transverse process is triangular and the rib T-shaped in cross section in the armor-bearing region, giving the maximum of strength, a wide bearing surface and a minimum expenditure of material. The significance of the great elevation of the transverse process is also apparent.

In the sacral and anterior caudal region the bases of the two rows of plates are approximated, and now the summit of the neural process broadens out to support their weight, as indicated in the third section (fig. 9). This broad-topped type of neural process ceases with the proximal third of the tail and indicates the beginning of the flexible aggressive weapon of offense bearing the sharp-edged spine-plates and caudal spines which are inserted obliquely into the muscular mass on either side in the angle formed between the neural process and the centrum (fig. 10).

Some of the larger spines, notably that described by Marsh as the type of *Stegosaurus sulcatus*, have the base divided by an asymmetrically placed longitudinal ridge (fig. 11) into two facets which seem to have borne against the neural process and centrum of the vertebra. This character is only present in very large spines which have a deep insertion into the underlying tissues. Ordinarily the insertion seems to be too shallow to give rise to the facets.

Owen has figured what he calls the "carpal spine" in *Dacentrus* (*Omosaurus*) *hastiger* from the Kimmeridgian of Wiltshire (Mon. Brit. Fos. Repts. pl. 77), which shows precisely

FIG. 11.

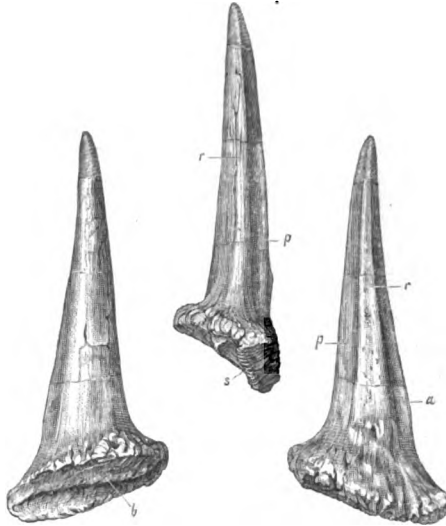


FIG. 11. Caudal spine of *Stegosaurus sulcatus*. After Marsh. 1/12 natural size. Dorsal, anterior and ventral aspects. *b*, the base showing longitudinal ridge.

this same structure of the base as in *Stegosaurus sulcatus*. *Dacentrus* is the probable Old World ancestor of *Stegosaurus*, but while the caudal spines are known, the presence of the armor plates has not as yet been demonstrated.

ART. XV.—*Times of Fall of Meteorites*; by O. C.  
FARRINGTON.

THE times of fall of meteorites may be studied with reference to the year, month, day and hour. The yearly falls should give evidence as to the frequency of the occurrence and exhibit periods if any occur. The falls by months should show the relation of meteorites to well-established star showers and the portion of the earth's orbit where meteorites are most frequently encountered. The falls by days should exhibit periodicity if any exists and variation in the uniformity of supply. Finally, the hours of fall should give the direction of movement of meteorites. Since new falls occur yearly, data for study of these points are obviously constantly on the increase. It is desirable, however, to make comparisons at intervals in order that any changes may be discerned. At the present time the admirable catalogues of Wülfing\* and others afford excellent means for the collection of such data. From these catalogues, with such additions and corrections as could be made from other sources, the writer has obtained record of 350 well authenticated meteorite falls of which the year and month are known, 327 of which the day is known, and 268 of which the time of day is known. In this number it has been sought not to include finds referred by residents of a locality to meteors which they had seen a year or more before, since the residents of most localities can, on the occasion of a meteorite find, recall a large meteor seen in that locality at some previous time. To connect this, however, without further reason with the meteorite found seems an unreliable method of procedure.

Considering the falls by years, it is well known that previous to the nineteenth century little reliable record of meteorite falls is available. Single falls are known for the years 1492, 1668, 1715, 1723, 1751, 1766, 1773, 1785, 1787, 1790, 1794, 1795 and 1796, and two falls each for the years 1753, 1768 and 1798. Also for the early part of the nineteenth century the record is not very complete, since during that period the possibility of meteorite falls was yet much doubted. However, the record may as well begin with 1800. From that year to the present, 331 falls may be accepted as well authenticated as to their month and year. During this period eleven years show no falls whatever. These years are—1800, 1801, 1809, 1816, 1817, 1832, 1839, 1888, 1906, 1908, and 1909. Of these the years of the present decade will probably have falls to their

\* Die Meteoriten in Sammlungen, Tubingen, 1807.

credit after a time, since the record of falls usually lags several years behind their occurrence. The largest number of falls shown in any year during the period is 11, in 1868. The years 1865, 1877 and 1886 show 7 each. All the other years show from 1 to 6 falls each. On the whole, therefore, the record seems to indicate a comparatively uniform supply of meteorites, which is the more remarkable when one considers the various chances affecting the observation of their fall. The record seems to afford no evidence of cycles or periodicity which can be traced with certainty. Still the record of years is perhaps not as satisfactory for establishing conclusions in this regard as is that of other periods. As the writer has shown elsewhere,\* at least 900 meteorites probably reach the earth yearly. Of these only an average number of 3 is recorded, so that it is evident that a large allowance must be made for unrecorded ones. Yet it is fair to presume that those recorded are typical of the whole, because while opportunities for observation of meteorite falls have probably continually increased in number since 1800, the record by decades shows that the decade from 1860 to 1870 considerably exceeded in number of falls either of the two succeeding ones.

Passing from the falls by years, the falls by months may be examined. Such an examination should have an especial significance in showing the relations which meteorites may have to well-known star showers. Two of the best known of these showers occur in August and November. If meteorites are related to these, these months should show a larger fall than others. If meteorites are not related to these, no special increase for these months should be shown. On compiling the results the latter proves to be true. The months exhibiting the greatest number of falls are May and June. The number for November falls below the average and that for August rises only slightly above. The evidence from this record is therefore that meteorites are not related to the best known star showers. It is fair to presume that the record by months will be somewhat influenced by the time that observers are most abroad. Most of the observations of meteorite falls are made in the northern hemisphere and in this hemisphere observers are more likely to be out of doors and hence more likely to observe the fall of meteorites in the summer than in the winter months. The record shows that as a whole the number of falls recorded is less for the winter than the summer months, yet the number of falls cannot be influenced by that alone since the high record for May and June drops to nearly half that number in July. Further the months of August, September and October are

\* Pop. Sci. Mon. 1904, pp. 351-354.

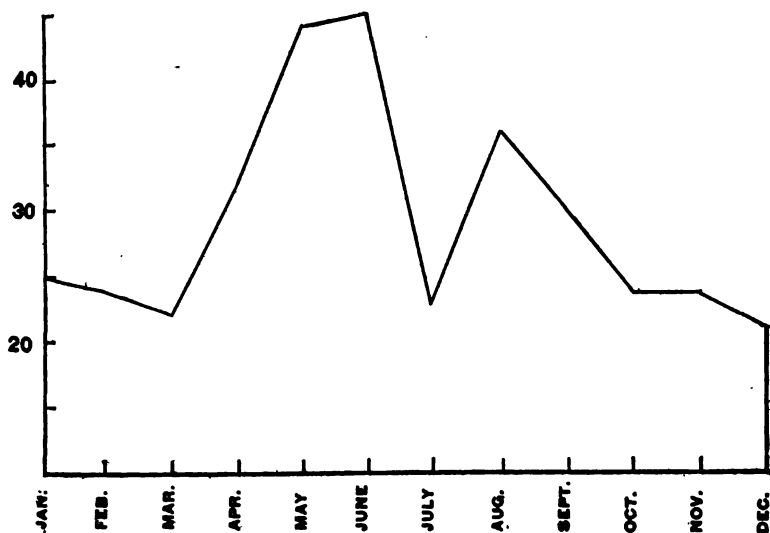


FIG. 1. Falls of meteorites by months.

equally favorable as regards weather for observations of meteorite falls with those of April, May and June, yet the latter period much excels the former in number of falls. The excess of falls in May and June must, therefore, be due to other causes than favorable conditions of observation and seems to indicate that in the portion of the earth's orbit passed through in these months there is an unusual number of meteorites. The full record for the different months is as follows:

Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
25	24	22	32	44	45	23	36	30	24	24	21 = 350

This record is shown graphically in the accompanying diagram, fig. 1.

Comparison of the falls of meteorites by months as here given with those of falling stars and fireballs as given by W. H. Pickering\* shows a marked difference of distribution. According to Pickering's list the falling stars and fireballs are much more uniformly distributed through the year than are meteorites, and the period of greatest number is from July to November. In May and June their number is at its minimum. Hence the record seems to show a difference in character between meteors and meteorites and furnishes *per se* a ground for questioning the gradation that has been supposed to exist between meteors and meteorites.

\* Popular Astronomy, No. 165.

Tabulation of meteorite falls by days of the year seems to show little of significance. The largest number of falls for any one day is five on October 13, and this is a month when the total number of falls is not large. Four days of the year show four falls each and 158, or nearly half the total number, no falls at all. The days without falls seem to be scattered indiscriminately through the year, without marked grouping or arrangement. The days showing falls aside from those mentioned have from one to three falls each without any marked grouping that is apparent. Such a record seems also to indicate that to refer a meteorite falling on the day of a star shower to such a shower is unsafe, especially if the observations are not sufficient to assign the two to the same radiant. Meteorite falls are so distributed throughout the year that the two occurrences might easily be coincident without being otherwise related.

Of all times of fall of meteorites the most satisfactory for study are probably the hours of fall, since the ratio of number of falls to number of hours is larger than to days, months or years. As is well known, the hours of fall show the direction of movement of meteorites, since (with a few minor possible obvious exceptions) meteorites falling from noon to midnight, or afternoon falls, must be moving in the same direction as the earth; while those falling between midnight and noon are moving in a direction opposite to that of the earth or else at a speed so slow that they are overtaken by it. While the hour of fall is not known of as many meteorites as is the year and month, yet of 268 sufficiently satisfactory records are available. Of these 268 falls 180 occurred in the time from noon to midnight, and 88 from midnight to noon. Meteorites, therefore, in the proportion of at least two to one, have direct motion and overtake the earth. Of the others it is probable that the majority have retrograde motion, since observations indicate that but few, comparatively, are traveling at so slow a speed as to be overtaken by the earth. As in the case of the months and the years, it is quite likely that here also considerable allowance should be made for conditions of observation. It is reasonable to expect that the number of falls recorded in the early morning hours would be less than that for other times, since mankind is generally asleep then. That some such allowance must be made is indicated by the records, for the number of falls from midnight to 6 A.M. is only 21, while from 6 A.M. to noon it is 67; from noon to 6 P.M. 122, and from 6 P.M. to midnight 58. Hence it seems probable that some of the diminution in the number of falls is due to lack of observers, although Newton\* concluded from studies of the orbits of the morning falls that the lack of observers had little to do with their scarcity.

\*This Journal (3), xxxvi, p. 10, 1888.

During the other periods of the day, however, the figures should be little affected by conditions of observation and there seems much reason for reaching the conclusion that the majority of meteorites have direct motion and travel at a velocity greater than that of the earth, or 18 miles per second. Here again meteorites differ from meteors, since the larger number of meteors fall in the morning hours. In times of fall by months, days and hours, therefore, the majority of meteorites differ from meteors. Their position in space, orbits and direction of movement must, therefore, differ correspondingly also.

Field Museum of Natural History,  
December 15, 1909.

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ART. XVI.—*Note on the Occurrence of Astrophyllite in the Granite at Quincy, Mass.; by L. V. PIRSSON.*

THE interesting note of Professor Warren on the finding of a pegmatitic facies of the alkalic granite of Quincy,\* and of the minerals it contains, recalls to the writer that he has recently noticed in a specimen of this rock the mineral astrophyllite. The occurrence is entirely a microscopic one and the crystals are too minute to be detected and tested megascopically, but as the real home of this rare and peculiar species, as shown in the few places in which it has so far been found—  
• Langesund fiord, South Norway; southern Greenland, and St. Peter's Dome, Colorado—is in the pegmatites of the alkalic rocks, it seems worth while to call attention to the occurrence in order that it may be placed on record, and that attention may be directed to the Quincy pegmatites in the hope of finding it in megascopic crystals. This is more especially necessary since from its dark or brownish color and excellent micaeous cleavage it is apt to be mistaken for biotite and overlooked. A chemical test for titanium will, however, serve to distinguish it readily from ordinary biotite and zinnwaldite, while lepidomelane, which might be expected in such associations of minerals, rarely contains more than a trace of this element. In this connection it might be stated that the writer has not observed any of the dark micas in the study of a considerable number of sections of the Quincy rock, although White† mentions it as occurring at times in minute flakes.

\* This Journal, vol. xxviii, p. 449, Nov. 1909.

† T. G. White, Petrography of the Boston Basin, Proc. Bost. Soc. Nat. Hist., vol. xxviii, No. 6, p. 131, 1897.



The astrophyllite was found in a rock of the usual Quincy type consisting of riebeckite, aegirite, microperthite and quartz, with zircon as the most common accessory mineral. It is in minute, elongated laths grouped into bunches and associated with the riebeckite. It was also observed intergrown with the riebeckite in such a way that the axis of elongation parallel to the cleavage was parallel with the vertical axis of the riebeckite; hence in section it appears as if wedged in between the hornblende cleavages. It was noticed that the riebeckite in this case had on its margin with the feldspar what the writer has drawn and figured as the interdentate texture,\* indicative of crystallization from eutectic conditions.

The astrophyllite was found to have the following properties: cleavage, excellent micaceous, and accepting this cleavage as the pinacoid  $b$  (010) the direction of elongation of the crystals is on the  $c$  axis and the directions of elasticity are  $a=c$ ;  $b=a$  and  $c=b$ ; strongly pleochroic,  $a$ , red-orange,  $c$ , lemon-yellow; absorption  $a > c$ ; refractive index  $> 1.7$ ; extinction parallel to the cleavage cracks; birefringence high  $> 0.04$ . In convergent light a single biaxial optic axis was obtained on the edge of the field; the limited number of crystals and their nearly parallel orientation did not permit of further investigation of the optic scheme.

These are the properties of astrophyllite and definitely determine it; from the micas, which it resembles in thin section, it is easily distinguished by the much higher relief, the reversal of the absorption scheme referred to the cleavage and the wide optic angle indicated.

There is yet much to be learned concerning this interesting mineral, whose formula is still uncertain, but which Brögger† believes to be  $\dot{R}_2\ddot{R}_2\text{Ti}(\text{SiO}_4)_2$ , in which  $\dot{R} = \text{H, Na, K}$  and  $\ddot{R} = \text{Fe, Mn}$ , and a new occurrence well investigated might be expected to throw much light upon its composition.

Sheffield Scientific School of Yale University,  
New Haven, Conn., Nov. 1909.

\* Contributions to the Geology of New Hampshire. No. III, On Red Hill, Moultonboro; this Journal, vol. xxiii, p. 273, 1907.

† Zeitschr. für Kryst., xvi, p. 212, 1890.

ART. XVII.—*The Crystallization of a Basaltic Magma from the Standpoint of Physical Chemistry*; by CLARENCE N. FENNER.

Introduction.

Scope of the article.

*Part I.*

Process of crystallization as demanded by the laws governing eutectiferous solutions.

Petrographic description of the Watchung basalt.

*Part II.*

The crystallization of a magma as affected by the law of mass-action.

Displacements of equilibrium within a solution effected by changes of temperature and pressure — van't Hoff's law.

Resorption of olivine in the Watchung magma.

INTRODUCTION.

WITHIN the last few years petrographers have recognized the important aid which might be rendered to the interpretation of the structure and history of igneous and metamorphic rocks by an application of the principles of physical chemistry. The discoveries which have been made regarding the laws governing the crystallization of solutions, the application of the phase-rule of Gibbs and of the law of mass-action, and the new conception of the phenomena of solid solutions, are believed to be capable of rendering very great assistance in interpreting the meaning of the structures with which petrographers have become familiar.

Although the applicability of these principles is generally conceded, very little has yet been done in applying them to specific cases.

In making a study of certain peculiar phases of the basalt which forms the Watchung Mountains in New Jersey, it came to be recognized that the rather unusual conditions which had attended its solidification had produced results which illustrated certain laws of the crystallization of solutions more perfectly than could be hoped for from the most elaborately devised laboratory experiments.

In a previous article\* the author has shown that the Watchung sheets were surface flows poured out over areas in which Triassic shales and sandstones were accumulating under conditions of continental sedimentation in structural valleys.† At most points the basalts present the dense, holocrystalline texture normal to this type of rock, but in certain areas the flows appear to have spread over the sites of shallow lakes, and

\* Features Indicative of Physiographic Conditions Prevailing at the Time of the Trap Extrusions in New Jersey. *Journ. of Geol.*, vol. xv, No. 4, May-June, 1906.

† See also J. V. Lewis, Annual Report N. J. State Geol. Survey for 1906.

AM. JOUR. SCI.—FOURTH SERIES, VOL. XXIX, No. 171.—MARCH, 1910.

many modifications of structure resulted. The chief effect, as regards the features which will be considered in this paper, was that the fused magma was rapidly chilled and rendered viscous. In places the stiffening liquid accumulated in masses of rounded or boulder-like forms similar to the "pahoehoe" of Hawaiian flows. The progress of crystallization was checked at various stages and the boulder-forms were crusted with basaltic glass, in which examination with the microscope shows few phenocrysts, while the more slowly cooling interiors of the boulders assumed the normal texture. Between the two types transitions occur, by which one may trace the passage of the microlites of the vitrophrys into the well-developed crystals of normal basalt.

The glass-encrusted boulders are especially well developed in an area lying between Paterson and Montclair Heights. Quarries have been opened at several points, as it has been found that this variety of trap is easily blasted and crushed for road-material. It has therefore been possible to obtain material for petrographic study unacted upon by weathering.

#### SCOPE OF THE ARTICLE.

Two principal features of the Watchung basalt will be considered, and in accordance with this the article is divided into two parts. Part I will deal with the order of crystallization of the constituent minerals, and it will be shown that, contrary to certain prevalent ideas regarding the order of succession of the minerals of a basaltic rock, the three constituents, plagioclase, diopside, and magnetite, began to appear almost simultaneously from the magma and continued to crystallize side by side until complete solidification was attained. In order to show that this result is demanded by the laws of crystallizing solutions, a very brief outline of these laws will be given as a preliminary to the petrographic study.

In Part II resorption-phenomena will be considered in connection with the resorption of olivine, a minor feature as regards the constitution of the rock, but very significant in its interpretation.

The law of mass-action will be considered in this connection, and the author will endeavor to show that the usual explanation of resorption is inadequate to explain certain phases of the phenomenon, but that a very satisfactory explanation may be derived from an application of van't Hoff's law.

#### PART I.

##### *Process of Crystallization as demanded by the Laws governing Eutectiferous Solutions.*

In order that the crystallization of a magma may proceed strictly along the lines indicated by eutectic laws, it is essential that

there shall be little or no reaction going on within the magmatic solution from the time that the initial crystals appear until the process of solidification is complete. In such cases the progress of solidification is very regular. Each compound present in the fusion has its temperature of solidification depressed according to the number of mols (gram-molecules) of other substances present and begins to appear at the appropriate point in the process of cooling. That mineral will first appear which, under the conditions stated regarding fusing-point, still has the highest temperature of fusion.

The first mineral may be regarded as that which is present in greatest excess over the eutectic ratio. Within a certain range of temperature it alone will be thrown out of solution. At a certain point, however, it will be joined by a second mineral, and these two in turn by a third. The composition of the solution approaches the eutectic ratio by the elimination of those constituents which are in excess. A sudden chill at any stage of the process causes a great increase of viscosity, which acts as a very effectual check to further crystallization. The result is the production of the greatly undercooled liquid of immense viscosity which is termed a glass. The composition of the glass depends upon the stage of progress toward the attainment of the eutectic ratio which has been reached. If no such interruption occurs, at the eutectic point the group of minerals forming the eutectic will crystallize out in the proper ratio. No further depression of the temperature of solidification can occur, and the loss of heat will be merely that due to the latent heat of fusion given up by each mineral in passing from the liquid to the crystalline phase. An application of the phase-rule of Gibbs confirms this conclusion, for at the eutectic point the number of phases exceeds the number of components by one, and no change of temperature or composition of the system can occur.

It is doubtful whether the solidification of a magma is ever quite such a simple process as is expressed in the form described, but though complications may ensue, the underlying principles of eutectics hold and should constitute a guide of great value in interpreting rock structures and history. In the solidification of the Watchung magma the reactions which would tend to obscure the process were of such nature that their results do not offer great obstacles. The only one of moment is that by which olivine was crystallized out and later was resorbed by the magma and did not again appear. This phenomenon will require explanation, but it is due to other physico-chemical laws, and the reaction was so nearly complete before the three final constituents, diopside, plagioclase, and magnetite, began to appear, that its effects may be disregarded for the present.

*Petrographic Description of the Watchung Basalt.*

In those portions of the Watchung flow in which chilling was most rapid the surfaces of the pahoehoe-like bosses were crusted with much glassy material. Apparently, however, judging from the study of a great number of slides, crystallization was under way and phenocrysts had begun to appear in the mass of flowing lava before the sudden chill occurred which stiffened it into a glass. The resultant glass shows a typical vitrophyric texture. The well-developed phenocrysts are surrounded by isotropic glass or by a groundmass in which glassy material is more or less mixed with the feathery forms of micro-lites. Under the generally accepted hypothesis, in a typical diabase consisting of magnetite, plagioclase, and diopside, the magnetite would be first to form, and its elimination from the magma would be complete before the plagioclase began to appear. These two are held to be followed by the third constituent, diopside, which occupies the space left by the other two. On the other hand, the manner in which the minerals should crystallize out, as demanded by the principles of eutectiferous solutions, is quite different, and in every case the sections examined conform to the latter requirements. No matter to what degree glass may be present in the slide, plagioclase and diopside appear side by side. It is evident that almost from the beginning of crystallization these two constituents were being eliminated simultaneously. At times it appears that the diopside is in somewhat preponderant amount, and at other times the plagioclase.

With regard to the magnetite the evidence is more obscure. The proportion of magnetite in the magma is not large and it seems to appear first as a dark dust. The exact point at which elimination from the fusion began is not clear, but it is certain that growth of magnetite grains continued while diopside and plagioclase were still forming.

Slide No. 103 shows a typical development of glass and phenocrysts. (See fig. 1.)

Probably three-fourths of the section is isotropic glass, uniformly pale green or light olive-green in the thin section. Scattered throughout are numerous phenocrysts of plagioclase and diopside. The plagioclase is in typical lath-like crystals reaching an ordinary maximum of  $0.2-0.3\text{mm}$  long by  $0.05\text{mm}$  wide. The diopside is developed in more nearly equidimensional forms of a characteristically stouter appearance. An exceptionally large crystal measured  $0.6$  by  $0.2\text{mm}$ . The outline is sometimes octagonal, but in general irregular. In many cases the plagioclase and diopside are closely associated, small clusters of mutually intergrown individuals lying in groups surrounded by glass. It is noticeable in such cases

that while the plagioclase laths are indented by the diopside crystals, the characteristic elongated form of the plagioclase is maintained.

These phenocrysts of diopside and plagioclase are bordered by dark plumose growths, or hair-like tufts, fading out at the

FIG. 1.



FIG. 1. Typical structure of the vitrophyric phase resulting from quick chill. (Slide No. 105.) Elongated crystals plagioclase, stouter forms diopside, matrix light-green glass, perfectly isotropic. Actual diameter of field 1.5mm.

periphery into the surrounding glass. Under the high-power objective they are resolved into innumerable microcrystalline growths, straight or curved, sometimes branching in lattice-like forms, thrown out from the boundaries of the phenocrysts. With the high magnification they exhibit the development sketched in fig. 2.

FIG. 2.

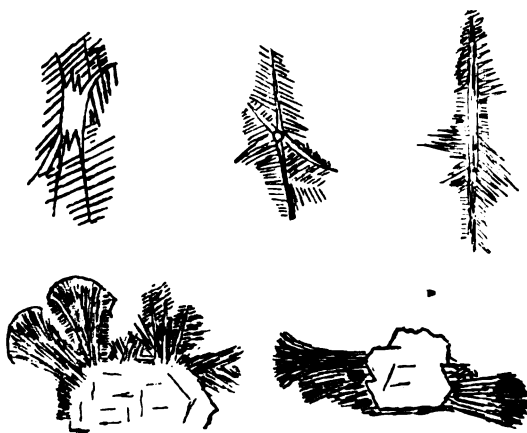


FIG. 2. Microlitic growth of plagioclase and diopside, greatly magnified.

The phenocrysts were probably formed during rather slow cooling in the flowing mass of lava, and the bordering microlitic growths represent the continuation of the crystallization during the initial stages of chilling, before increasing viscosity put a stop to the process. Their brown color seems best explained by the separation of magnetite dust at the same time that diopside and plagioclase were crystallized out. If this is true, the eutectic ratio had been reached, and if normal crystallization had been followed the continuation of the process would have taken the form of simultaneous growth of crystals of diopside, plagioclase, and magnetite. This was prevented by the increasing viscosity of the liquid, with which crystallization could not keep pace.

The almost simultaneous appearance of diopside and plagioclase at the initiation of crystallization, attended or followed after only a short interval by magnetite, would appear to demonstrate that the composition of the magma as erupted did not differ greatly from that required to form a eutectic of the three.

The only other feature of interest in the slide is the presence of a number of olivine crystals, which have been strongly attacked and resorbed by the magma. This phenomenon will be taken up later.

Slide No. 1 is almost a duplicate of No. 105 and exhibits the same set of phenomena, except that there is no evidence of olivine grains, and that the glassy groundmass shows with high magnification abundant brown dust. Diopside phenocrysts are a very minor constituent but plagioclase is abundant.

In No. 57 the chilling was apparently a little less sudden, for the phenocrysts have a tendency to blend with the plumose microlitic borders and a smaller proportion of the slide is occupied by strictly undifferentiated glass.

Slides 30, 85, and 90 are other examples showing essentially the same relations of phenocrysts, microlites, and undifferentiated glass. In No. 132 (fig. 3), the microlites are seen to be spreading over a greater portion of the field, and in No. 2 a further stage is shown.

This latter slide was taken from the same hand specimen as No. 1, but whereas the portion of the rock from which No. 1 was taken presented a decidedly vitreous appearance, that from which No. 2 was prepared was a little farther removed from the chilled crust and was of a felsitic character. Microscopic examination confirms the deduction which would naturally be drawn. In No. 1 the phenocrysts are merely bordered by plumose microlites and a large part of the section is undifferentiated glass. In No. 2 the microlites have spread over the entire field not occupied by the phenocrysts and no glass can

be perceived. Instead there is a beautiful development of tufts and sheaves of feathery microlites occupying the entire groundmass. The phenocrysts, as before, show groups of diopside and plagioclase in mutual intergrowth. The general dark brown color of the groundmass appears to be due to dust

FIG. 3.



FIG. 4.



FIG. 3. Microlitic additions to phenocrysts of diopside and plagioclase. (Slide No. 132.) Diameter of field 1.5mm.

FIG. 4. Intermediate texture between microlitic and holocrystalline. (Slide No. 58.) Diameter of field 1.5mm.

and grains of magnetite developed along the lines of growth of the feathery microlites and outlining their form.

In slides No. 96 and No. 58 (fig. 4) a step in advance is shown toward the holocrystalline texture of a normal basalt resulting from moderately slow cooling. The sharply defined outline of the phenocrysts has been lost and their borders fray out into the finely crystalline groundmass. The groundmass itself is coarser than in the earlier described sections and the subhedral crystals are comparable in size to the phenocrysts. Some of the magnetite is in distinct grains, but much of it is still in the form of a dark dust lying between the lighter minerals.

Nos. 98, 99, and 18 (Photograph, fig. 5) show successively coarser phases of crystallization, and Nos. 23, 24, and 25 show the normally developed texture of these basalts. Nos. 47 and 64 represent the maximum of coarseness of crystallization attained.

In the normally crystallized basalt the essential constituents are plagioclase, pyroxene (diopside), and magnetite, the first two in crystalline forms, the last in dust, granules, or trellis-like groups. (See fig. 6.)

The plagioclase is in lath-shaped crystals, euhedral to subhedral, generally showing two or three stripes of albite-twinning lamellæ. Pericline twinning is rarely present. Its average



dimensions are  $\cdot 15$  by  $\cdot 03^{\text{mm}}$ , but occasionally crystals of larger size up to  $1^{\text{mm}}$  in length, and more nearly equidimensional, are scattered through the mass. It comprises, roughly speaking, two-fifths of the whole.

FIG. 5.



FIG. 5. Photograph of normally crystallized basalt. (Slide No. 18.) Diameter of field  $2\frac{1}{4}^{\text{mm}}$ .

FIG. 6.



FIG. 6. Ophitic texture of normally crystallized basalt. (Slide No. 47.) Plagioclase laths, diopside granules, and crystals and dust of magnetite in mutual intergrowth. The magnetite is mostly included in the diopside, but partly also in the plagioclase. Diameter of field  $1\cdot 5^{\text{mm}}$ .

Extinction angles measured on symmetrically extinguishing albite twins give maxima of 33–34 degrees. This indicates a medium labradorite of about the composition Ab 40 An 60.

The pyroxene is in stouter forms of an irregularly angular outline. The grains show a tendency to coalesce in groups of

individuals of different extinction. Single units show dimensions of  $0.2$  by  $0.15^{\text{mm}}$  with occasional larger grains up to  $0.5^{\text{mm}}$  in size. The crystals are almost colorless, with a faint tinge of brown or green. In many slides twinning is a common characteristic. Twinning and composition plane the orthopinacoid (100). Polysynthetic basal twinning is absent. Optical character biaxial and positive. No difference in dispersion between red and violet can be perceived. Prismatic cleavage often poor in the small grains but well developed in the larger. Birefringence  $0.020 - 0.022$ .

Extinction measured from the ortho-pinacoidal twinning plane to the axis of minimum elasticity,  $Z$ , gave angles of  $45$  degrees. The mineral is evidently not pure diopside, but whether it varies toward hedenbergite or toward augite would be difficult to determine without chemical analysis. It is referred to as diopside. The quantity is somewhat in excess of the plagioclase.

The magnetite is seldom in euhedral crystals, more often in fine dust or in trellis-like or fir-tree groups. During the crystallization of the plagioclase and diopside the magnetite appears to have been mechanically pushed aside until the last stages of crystallization were reached, and then included within the final crystals of the lighter constituents, to which it gives a dark brown color. Even in the final stages the plagioclases seem to have had the power to free themselves of the magnetite dust fairly effectually, and most of it is included within diopside grains. A small portion is enclosed within irregular patches of light-green chloritic material, which may represent resorbed olivines subsequently chloritized.

In addition to these essential constituents there are a number of well-defined areas of what was originally olivine, but which show strong resorption and later alteration to serpentine and chlorite.

The magnetite in these rocks is probably titaniferous, as it gives rise on decomposition to milky-white leucoxene.

In examining those slides which have the texture normal to basalts the plagioclases appear to have the crystals developed in more nearly euhedral forms than the diopside, and it might be argued that this is confirmatory of the generally accepted view that the growth of the plagioclases was finished before that of the diopside began, and that the latter mineral molded itself around the plagioclase. It is only necessary, however, to devote a little study to the question to determine that this is emphatically not the case. In those vitrophyric rocks first described (e. g. No. 105 and No. 57) in which plagioclase and diopside undoubtedly developed while swimming freely in a

# BRIEF ANNOUNCEMENTS.

Recent pressure of business has hindered me from compiling a detailed list of new minerals arrived. I wish to mention, however, a new lot of the metallic Awaruite from Smith River, California, ranging in sizes from  $\frac{1}{4}$  inch to 1 inch. These interesting metallic pebbles are of scientific value on account of the nickel being associated with the iron in the metallic state. Considering the great amount of attrition which they received from stream action, I find them very well preserved and deserving a place in every collector's cabinet. These range in price from 25 cents to \$2.00.

Although the finest of the recent Iceland Zeolites and Franklin Furnace minerals have been sold off rapidly, I still have choice examples of these splendid specimens at reasonable prices.

Having received some excellent shipments representing chiefly Hungary, Saxony and other celebrated German localities, of which specimens I was unable to prepare a list in time for this issue, I shall be pleased to furnish further data on request. I noted in these shipments several specimens of the rare Argyroditite and other silver minerals too numerous to mention.

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I recently received additional minerals from Colorado and can now supply any reasonable demand in Tellurides, native Tellurium, Amethystin-Quartz, Calciovolborthite and Carnotites. Prices on request.

I have also considerably increased my stock of the celebrated California Tourmalines so that I now feel that no dealer has ever had the quality and quantity of these specimens that I have, while the prices of same have been somewhat lowered, considering their value, as compared with former prices.

Have also made a recent addition to my stock of the Reconstructed Rubies, Sapphires and Pink Topaz, which places me in the best position for supplying the demands of my customers.

It would be advisable for those interested in the above to have their names on my mailing list, and I shall be pleased to send on approval for inspection and selection anything that may interest my patrons.

Information as to special lists and prices of individual specimens cheerfully given.

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**A. H. PETEREIT,**  
**81—83 Fulton Street, New York City.**

THE

# AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

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ART. VIII.—*The Nitrogen Thermometer from Zinc to Palladium*; by ARTHUR L. DAY and ROBERT B. SOSMAN; with an Investigation of the Metals, by EUGENE T. ALLEN.

CONTENTS:

1. Introduction and Plan.
2. Apparatus.
3. Details, Errors, and Corrections.
  - A. Temperature of Gas in Bulb.
  - B. Definition of Temperature by Measurement of Pressure.
  - C. Transference of Temperature by the Thermoelement.
  - D. The Fixed Points.
4. Experimental Data and Calculated Results.
  - A. Expansion Coefficient.
  - B. Gas Thermometer Data and Fixed Points.
5. Interpolation between the Fixed Points.
6. Analysis of Metals. (By E. T. Allen.)
7. Conclusion.

1. *Introduction and Plan.*

THE measurements of absolute temperature here offered were undertaken in direct continuation of those published from the Geophysical Laboratory two years ago,\* with the purpose of extending the gas scale to 1600°, or as near it as might prove practicable. Except in explanations of new or particularly important features, descriptive details have accordingly been omitted here and must be sought in the first paper. Substantially the same methods and apparatus have been employed throughout.

One conclusion in particular which was brought out at that time is entitled to even greater emphasis, namely, that the existing uncertainties in the absolute temperature scale at 1000° and above are the result of experimental limitations and not of any failure of the principles involved. The experimental conditions were scrutinized with great care throughout the first investigation, and not only were the known correction factors all redetermined, but their total magnitude was reduced nearly 75 per cent. This success, after so long and painstaking

\* Arthur L. Day and J. K. Clement, this Journal (4), xxvi, 405-463, 1908.

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ing a study of the correction factors, led the authors to believe that the upper end of the existing gas scale (melting point of pure copper), which has been vacillating in a somewhat irregular way in various hands for three-quarters of a century, had been finally confined to the limits  $\pm 0.5^\circ$ , or within  $1^\circ$ . Although this ideal had been affectionately cherished for a good many years, its triumph has been shortlived. The present investigation has discovered a source of error which appears to have passed unnoticed before, which operates to raise the temperature scale at the copper point about  $1.4^\circ$ . This kind of history has repeated itself with remarkable persistence all through the record of high temperature research, and may, of course, do so again, but the limits of uncertainty are continually becoming narrower, and it appears to the authors unlikely that further investigation will again reveal errors aggregating  $1^\circ$ .

On the other hand, the detailed study of temperature distribution about the bulb (page 102) in which the present error was discovered, cannot but convince an experienced observer that the limit of refinement in an electrically heated air bath has been practically attained, and that higher accuracy in gas thermometry must be sought in a liquid bath which can be stirred.

Since the publication of the Reichsanstalt scale\* in 1900, it has remained the standard for all temperature measurements between  $400^\circ$  and  $1100^\circ$ . Its limit of accuracy as an absolute scale was estimated to be about  $3^\circ$  at  $1000^\circ$ .

The work of Day and Clement was mainly directed to the following essential features of the problem of absolute measurement with a constant volume gas thermometer: (1) An absolutely gas-tight bulb of definite volume; (2) uniform distribution of temperature over the bulb surface during the measurements; (3) the reduction of the error due to the unheated capillary tube connecting the bulb with the manometer; (4) a more accurate determination of the expansion coefficient of the bulb itself.

The results accomplished by them in these directions may be outlined seriatim as follows: (1) The bulb chosen (90 parts platinum, 10 parts iridium) is quite rugged enough for measurements as high as  $1500^\circ$ , and no difficulty was experienced in maintaining a nitrogen atmosphere in it without loss by diffusion or leakage. At high temperatures the material becomes considerably softer, but with the help of a gas-tight furnace in which nitrogen could be maintained at the same pressure outside the bulb as within, neither diffusion through the bulb walls nor mechanical strain was encountered. Variations in the zero point of the thermometer, which have been

\* L. Holborn and A. L. Day, *Ann. d. Phys.* (4), ii, 505, 1900; *this Journal*, (4), x, 171, 1900.

very persistent and inaccessible errors throughout the history of gas thermometry, have therefore now become practically negligible. This gas-tight furnace possessed the further advantage that the initial pressure of the gas, and consequently the sensitiveness of the instrument, could be varied within considerable limits. A sensitiveness as great as  $1^{\text{mm}}$  of the manometer scale per degree was regularly employed. The iridium alloy has the disadvantage that platinum thermoelements, which are necessary for recording variations in the temperature over the surface of the bulb, and for transferring the gas thermometer temperatures to standard melting points, become contaminated in the presence of iridium at all temperatures above  $900^{\circ}\text{C}.$ ; the higher the temperature and the longer the time of exposure, the greater the degree of contamination.

(2) It was sought to obtain a uniform temperature over the surface of the bulb by winding the (pure platinum) furnace coil on the inside of a refractory magnesia tube which contained sufficient iron oxide and other impurities to be a fairly good conductor of heat. The winding was somewhat closer at the ends than in the middle. This was further supplemented by secondary coils of smaller wire extending a few centimeters into the tube from each end. The current in the three coils could be independently regulated with the help of thermoelements attached to the bulb and giving its temperature at the middle and upon each shoulder (positions 2, 4, and 6, fig. 1). When these temperatures had been adjusted so that the differences between them were smaller than  $0.5^{\circ}$ , it was assumed that the temperature over the whole surface of the bulb was constant within those limits. (For the oversight in this assumption, see pages 99 and 102.)

(3) The platinum capillary and connections between the bulb and the manometer were much diminished in volume. Compared with the total volume of the bulb ( $195.7^{\text{cc}}$ ) this connecting volume amounted to  $.0015$  in their instrument, and reduced the total correction for the "unheated space" to less than  $5^{\circ}$  at  $1100^{\circ}$ , a correction factor not more than one-fourth as large as the best previous attainment in this direction. The uncertainty of the temperature distribution in the "unheated space" was perhaps 10 per cent, making the probable error from this source about  $0.50^{\circ}$ .

(4) A special bar  $25^{\text{cm}}$  in length, made up from the same alloy as the bulb, was provided with a scale and its length measured in a special form of comparator at temperature intervals of  $50^{\circ}$  up to  $1000^{\circ}$ . The expansion was found to be  $10^4\beta = 8.84 + 0.00131t$ , with an error of about 0.5 per cent. An irregularity was detected both in the expansion and subsequent contraction in the region below  $300^{\circ}$ , which appeared variable with the rate of cooling or heating, and in character resembled the hysteresis which appears in a bar which has been subjected

to stress. If the bar was cooled down very slowly, it returned nearly to its initial length; if cooled rapidly, it required several days to return to its original dimensions. This irregularity makes up most of the 0.5 per cent uncertainty mentioned above.

*Plan.*—Above 1100° considerable uncertainty has existed in the temperatures of various fixed points. The melting point of nickel, considered as 1484°,\* has been frequently employed. The curve of the platinum-rhodium thermoelement, extrapolated beyond the copper-point, has been still more generally used, but like any extrapolation, may lead to quite erroneous results. The only gas thermometer comparison that has been made in this region is that of Holborn and Valentiner,† but by their own estimate the accuracy of the upper portion of their scale is not greater than  $\pm 10^\circ$ . The chief purpose of our work was, therefore, to establish the temperature of several fixed points between 1100° and 1600° and to find what curve is followed by the platinum-rhodium thermoelement in this region, with an accuracy comparable to that obtained in the lower portion.

The plan of the work is simple. It consists, first, in selecting certain fixed thermometric points, usually melting points of metals, and in determining their reproducibility; second, in making a measurement of the true temperature on the nitrogen scale at or close by one of these fixed points; third, in transferring this known temperature by means of a thermoelement over to the fixed point in question. This transference by the thermoelement is necessary because the thermometer bulb cannot be put directly into melting or solidifying substances at high temperatures. The relation of electromotive force to temperature for any particular kind of thermoelement does not enter into the problem when the temperatures measured are close to the fixed points; a linear correction is then abundantly accurate. The interpolation curve, for any element, between the fixed points established by the gas thermometer, is therefore a separate matter.

The questions which remain to be answered are, then: (1) How exact and uniform can the temperature of the gas in the bulb be made (independently of any effort to measure this temperature)? (2) How accurately can its pressure be measured in order to establish that temperature on the nitrogen scale? (3) How accurately can this temperature be transferred from the thermometer and compared with the fixed melting point? (4) How accurately can the fixed points be reproduced for purposes of calibration of secondary measuring devices?

As has been stated, our experience has convinced us that the most of the variations in the gas scale temperatures of the

\* Holborn and Wien, *Wied. Ann.*, xlvii, 107, 1892; and lvi, 360, 1895.

† *Ann. d. Phys.* (4), xxii, 1, 1907.

fixed points commonly in use, as given by various observers, are due, not to differences in the properties of different gases used, nor to differences in pressure, nor to differences between the constant-volume and constant-pressure scales, all of which have been frequently discussed from the theoretical standpoint; but to systematic errors residing in the apparatus and the methods employed. A large portion of the present work has therefore been devoted to finding out experimentally the effect of variations in all those conditions which might affect the results systematically.

## 2. *Apparatus.*

In all essential particulars the gas thermometer apparatus is that developed by Day and Clement and already described by them in detail (*loc. cit.*). It consists of four principal parts: (1) bulb, (2) furnace, (3) furnace jacket, and (4) manometer.

(1) *The Bulb.*—A great deal depends upon the material of which the bulb is made. Primarily and obviously, the bulb must be able to hold the expanding gas without absorbing or losing any portion of it throughout the temperature range of the measurements.

A secondary requirement, the importance of which increases rapidly when high accuracy is sought, is that it shall be possible to use several thermoelements in the furnace with the bulb without their readings being endangered by contamination from the bulb material. As long as this intermediary role of the thermoelement remains a necessary one and alloys of platinum continue to provide the only successful bulb material, the contamination\* of the platinum wire of the element by the alloyed iridium or other platinum metal in the bulb will remain a serious consideration in all temperature measurement above 900°.

Although the platin-iridium bulb served well as a gas container, the contaminating effect of the iridium upon the thermoelements made the life of the latter, for measurements of such extreme accuracy, very short. Accordingly, at the close of the first series of experiments, a change was made from the platin-iridium bulb to one of platin-rhodium (80 parts platinum, 20 parts rhodium) 160<sup>mm</sup> long and 47<sup>mm</sup> in diameter. Inasmuch as one of the wires of the thermoelement itself contains 10 per cent of rhodium to which the platinum wire is always exposed (and which gradually contaminates it, too, although very slowly), it was thought that the substitution of a rhodium alloy in the bulb might serve to retain the necessary qualities of stiffness and regularity of expansion with a minimum of disadvantage in the matter of contamination. These expecta-

\*For a detailed account of the behavior and treatment of contaminated thermoelements, see Walter P. White, *Phys. Rev.*, xxiii, 449, 1906.



tions have been completely realized. Although the rhodium alloy is less rigid at temperatures of  $1000^{\circ}$  and beyond than the iridium alloy, and requires more careful adjustment for equal pressure within and without, no sagging of the bulb walls or deformation from the gas pressure has appeared up to  $1550^{\circ}$ . Meanwhile, the contamination of the thermoelements in the presence of the rhodium alloy is now reduced in magnitude about 80 per cent for a given temperature and time of exposure.

(2) *The Furnace.*—The common practice of recent observers (Callendar, Harker, Holborn and Day, Jacquierod and Perrot, Day and Clement) has been to use a cylindrical bulb in which the length was three or four times the diameter, enclosed in a concentric furnace tube (air bath) heated by the electrical resistance of a coil of wire wound upon or within it. To this bulb the heat is applied radially over its cylindrical surface, but no heat is supplied at the ends. The furnace tube itself and the winding of the coils have been changed at different times and in a variety of ways in order to vary the distribution of the heat supply. The arrangement used in most of our experiments consisted of one main coil of platinum wire  $1.2^{\text{mm}}$  in diameter, wound on the inside of a refractory magnesia tube  $36^{\text{cm}}$  long and  $2^{\text{cm}}$  thick. As has been our habit for some years, the windings near the ends of the coil are somewhat closer together than those at the middle, but this device is not of itself sufficient\* to compensate for differences of temperature along the bulb at all temperatures. In a particular case a favorable arrangement will provide an almost perfect temperature distribution at  $500^{\circ}$ , but will overcompensate the ends at  $1000^{\circ}$  sufficiently to spoil the measurements. The conductivity of the bulb metal is wholly inadequate to help out this overcompensation by conveying surplus heat from the ends to the middle of the bulb. On the other hand, a change in the winding which will correct the overcompensation at  $1000^{\circ}$  provides insufficient compensation at  $500^{\circ}$ . The arrangement which has become usual with us is therefore to wind the coil somewhat more closely at the ends than in the middle, with the idea of providing partial compensation for the inevitable heat losses at the ends of the furnace in this way, and in addition, to insert supplementary coils of smaller wire in the ends of the furnace tube in order to provide a small, independently regulated heat supply which can be superposed upon that of the main coil and give the desired uniformity at any temperature likely to be employed. A furnace tube arranged in this way, except for accidental variations, caused, for example, by the flaking off of the fur-

\* Day and Clement, loc. cit., p. 411.

nace lining, affords uniform temperature distribution over a length of 20<sup>cm</sup> in the center of the tube for a range of temperature from 300° to 1550°, and no one temperature is more difficult to regulate than another. This arrangement contains a limitation, however, of considerably greater magnitude than was at first suspected. The ends of the bulb face the comparatively cold ends of the furnace tube and radiate a sufficient quantity of heat toward these cold ends to reduce the temperature of the end surfaces of the bulb some 6 or 8° below the mean temperature of the cylindrical surface.

In so far as this may appear to be a rather obvious condition to be overlooked, it may be remarked parenthetically that it is a common practice of physicists to assume that the temperature is constant over a radial cross-section near the center of a cylindrical furnace which is reasonably long in comparison with its diameter. With this in mind, the probability is even greater that a metallic conductor only 4<sup>cm</sup> in diameter (the end surface of the bulb) perpendicular to the axis in such a furnace will have a uniform temperature between its center and periphery. The fact is that neither of these assumptions is justified, even in furnaces as long as twenty times the diameter. This was shown in a number of actual measurements made under varied conditions, differences of several tenths of a degree being found as low as 300°, and of several degrees at 1000° and higher.

This situation demonstrates the futility of depending upon metallic conductivity (of platinum) to equalize a steep temperature gradient, and again emphasizes the fact, if further emphasis is necessary, that the air bath, or, more explicitly, the temperature distribution within the heating chamber, is the most uncertain factor remaining in gas thermometry.

On account of difficulties in manipulation and accidental leakage into the thermoelement system, we preferred not to introduce additional heating coils into the furnace tube, and accordingly undertook to stop the loss of heat by inserting thin, platinum-covered diaphragms opposite the ends of the bulb. The situation was still further safeguarded, in exchanging the platin-iridium for the platin-rhodium bulb by adding a reentrant tube at the lower end of the bulb, to enable us to measure the actual temperature prevailing at its center as well as over the surface. In this way, we thought to obtain a more representative integral of the surface temperature and a competent comparison of this integral with the temperature actually prevailing at the center of the bulb.

(3) *The Furnace Jacket.*—The furnace jacket was water-cooled and could be closed air-tight around the furnace and bulb together, so that the pressure could be maintained the same within and without the bulb to avoid deformation.

(4) *The Manometer*.—The bulb communicated, by a capillary tube leading out through the furnace jacket, with the manometer, which consisted of two glass tubes communicating through a steel reservoir. At the top of the shorter arm, where the capillary joined it, was a fixed reference point to which the mercury was brought for each measurement of the pressure. A detailed description of the manometer will be found in the previous paper.\*

### 3. Details, Errors and Corrections.

The gas thermometer for high temperatures has now reached a stage of development where it becomes necessary to examine many small sources of error. These will be discussed in the succeeding paragraphs without attempting to classify separately the variable errors of observation, and the systematic errors which may arise from conditions of the measurements or from constant corrections.

To bring out the plan of investigation of these errors, it will be well to recall the derivation of the gas thermometer formula. The gas scale, as is well known, is defined by the relation

$$\frac{pv}{1 + \alpha t} = K \quad (1)$$

in which  $K$  and  $\alpha$  are constants and  $t$  is a function of  $p$  and  $v$ , the pressure and volume of a fixed mass of the gas.  $K$  and  $\alpha$  are determined by two further conventions:

When  $p = p_0$  and  $v = v_0$  (at melting point of ice),  $t = 0$  (2)

When  $p = p_{100}$  and  $v = v_{100}$  (at boiling point of water),  $t = 100$  (3)

It is then evident that

$$\alpha = \frac{p_{100} \frac{v_{100}}{v_0} - p_0}{100 p_0}$$

which defines  $\alpha$  as the mean pressure coefficient of the gas between  $0^\circ$  and  $100^\circ$  (when  $v_{100}$  and  $v_0$  are nearly equal); and

$$K = p_0 v_0.$$

The temperature,  $t$ , is therefore defined by the formula:

$$t = \frac{p \frac{v}{v_0} - p_0}{\alpha p_0} \quad (4)$$

the scale depending upon the gas chosen, the value of  $p_0$ , and the ratio  $\frac{v}{v_0}$ . In the theoretical constant-volume thermometer,

\* Loc. cit., p. 415, and this article, p. 107.

this ratio  $\frac{v}{v_0}$  is unity, but in the experimental constant-volume thermometer it always varies considerably from 1. We have preferred therefore to treat equation (4) as the fundamental equation, introducing in place of  $\frac{v}{v_0}$ , however, the proper function of the expansion coefficient of the bulb material.

Since apparatus designed for high-temperature work is not suited for the most accurate determination of  $\alpha$ ,  $\alpha$  has been treated in this discussion as a separately determined constant.

In the experimental gas thermometer, there is always a small space in the tube connecting with the manometer which is at various temperatures other than  $t$ . The pressure ( $p'$  or  $p_0'$ ) actually measured is not therefore the  $p$  or  $p_0$  of the formula. Imagine that this supplementary space is heated up to the uniform temperature  $t$ , without any change in its volume, and let the resulting corrected pressure be  $p$  (or  $p_0$  as the case may be). Furthermore, let

$V$  = volume of bulb at  $t^\circ$ .

$V_0$  = " " "  $0^\circ$ .

$v_1$  = " " " unheated space" which is at temperatures other than  $t$  (or than  $0^\circ$ ).

$t_1$  = temperature of this space.

$\beta$  = linear expansion coefficient of the bulb material.

Under these conditions, formula (4) becomes :

$$t = \frac{1}{p_0 \alpha} \left[ p \frac{V + v_1}{V_0 + v_1} - p_0 \right]$$

$$= \frac{1}{p_0 \alpha} \left[ p \left( 1 + \frac{3\beta t}{1 + \frac{v_1}{V_0}} \right) - p_0 \right]^* \quad (5)$$

In this formula  $\frac{v_1}{V_0}$  is a very small correction term ; while the important quantities to be measured are  $p_0$ ,  $p$ ,  $\alpha$  and  $\beta$ . The ratio  $\frac{v_1}{V_0}$  becomes of importance, however, in determining the corrected pressure  $p$  from the measured pressure  $p'$ . The derivation of this correction is as follows :

The mass of the gas in the unheated volume under the actual conditions of measurement is proportional to  $\frac{p'v_1}{1 + \alpha t_1}$  ;

$$* \quad \frac{V + v_1}{V_0 + v_1} = \frac{\frac{V}{V_0} + \frac{v_1}{V_0}}{1 + \frac{v_1}{V_0}} = \frac{1 + 3\beta t + \frac{v_1}{V_0}}{1 + \frac{v_1}{V_0}} = 1 + \frac{3\beta t}{1 + \frac{v_1}{V_0}}$$

the mass of the gas within the bulb is proportional to  $\frac{p'V}{1+at}$ .

If we now suppose the unheated space raised to the uniform temperature  $t$  without change of volume, the pressure being thereby raised to  $p$ , the total mass is proportional to  $\frac{p(V+v_1)}{1+at}$ .

Therefore,

$$\frac{p'v_1}{1+at_1} + \frac{p'V}{1+at} = \frac{p(V+v_1)}{1+at}$$

whence

$$p-p' = p' \left( \frac{v_1}{V+v_1} \cdot \frac{at-at_1}{1+at_1} \right)$$

This correction is easily calculated and tabulated; or, better, the factor in parenthesis (in the second member of the equation) is plotted against temperature. In practice, the volume  $v_1$  is divided into three portions at temperatures  $t'_1$ ,  $t''_1$ , and  $t'''_1$  as explained on p. 109, and the corrections obtained from the curve for each of these portions are simply added together to obtain the total correction  $p-p'$ . With these corrected pressures,  $p_0$  and  $p$ , the temperature  $t$  is calculated by formula (5) on page 101.

The discussion of errors and corrections will now be taken up under the general outline sketched on page 96.

*A. Temperature of the Gas in the Bulb.* (a) *Uniformity.*—Above the temperatures where a liquid or vapor bath can be used to secure uniformity, the differences of temperature between different parts of a furnace has always been a serious limitation to the accuracy of the gas thermometer. This variation, even in a furnace containing well-conducting materials, is much larger than has usually been assumed, and the three equalizing factors of conductivity, radiation, and convection by air-currents, are all credited with much greater influence in bringing about uniformity than they really possess. It sometimes happens that our faith in these factors is inversely proportional to our quantitative information.

To remove this source of uncertainty, Day and Clement introduced two auxiliary heating coils in the furnace, one at each end, and by varying the three independent currents, brought the temperature at the middle and at both ends, on the outside of the bulb, to equality.

In our first measurements with the new bulb, the end elements were placed on the axis of the bulb, in positions 1 and 9 (fig. 1), instead of on the outside surface. It became evident at once that the supporting tube in the bottom of the furnace, used in the work of Day and Clement, had a consid-

erable cooling influence on the central portion of the bottom, an effect which would tend to make their results low. This effect was largely obviated by using, in place of the heavy magnesite tube, a thin Marquardt porcelain tube in the top of which was placed a Marquardt crucible, cut out into a three-pronged support. The bottom of the crucible acted as a screen to prevent radiation from the bottom of the bulb, and the smaller thickness and thermal conductivity of the tube practically prevented the loss of heat from the bottom by conduction. Later, a second diaphragm was added, about 1<sup>cm</sup> lower down, primarily

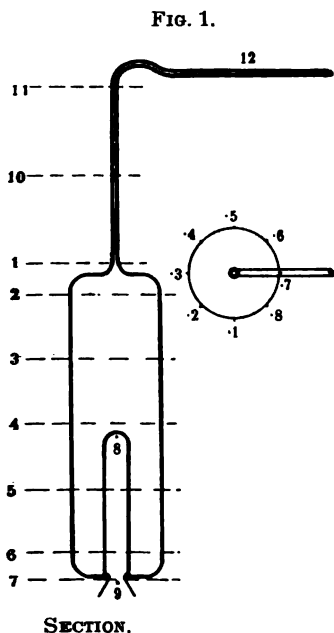


FIG. 1. Numbers indicate the positions of the thermoelements grouped about the bulb.

FIG. 1a. A photograph of the bulb made after the palladium-point determination showing all the elements and the diaphragms in position.

for the purpose of centering the tube and bulb in the furnace, but without noticeable effect on the temperature distribution.

In addition to the three thermoelements mentioned, a fourth was located inside the reentrant, in position 8.\* Several trials under varied conditions confirmed the fact that this element, when the other three were set equal, was 2° to 3° hotter than the one on the outside. A thorough exploration of the dis-

\* See fig. 1, and note, p. 104.

tribution of temperature over the surface of the bulb was therefore undertaken.

Since the number of wires which could be led out through the packed joints was limited, the plan was adopted of using the bulb itself as a differential thermoelement, single platinum wires being tied to the bulb at points whose temperature was to be determined. Each of these wires formed, with the platinum of the standard element tied to the bulb at the middle, a differential element which would read zero if the wires were alike and if no difference of temperature existed between the two points on the bulb.

The relation of the wires was established by sealing each in turn to the platinum of the standard, and measuring their E.M.F. at various temperatures. The readings varied, according to the quality of the wire, from 0 to 40 microvolts. The method of evaluating differences of temperature, when such existed, is discussed on page 118.

The distribution of temperature lengthwise of the bulb was first investigated, and auxiliary wires were placed at the levels 1 (base of stem), 2 (top shoulder), 6 (bottom shoulder), 7 (bottom, outside of funnel), in addition to thermoelements at 4 (middle outside), 8 (inside reentrant), and 9 (bottom, just inside of funnel).\*

With this system of thermoelements, it was found that at 1082°, when 9 was brought to equality with 4 and 1, the bottom of the bulb was superheated 6 to 8° at position 6, and about 4° at 7, due entirely to the fact that the thermoelement at 9, not being in contact with the bulb, lost sufficient heat by conduction and radiation downward to keep its temperature below that of the metal surrounding it. The element at 8, on the other hand, received heat by conduction up the reentrant tube and by radiation from below, which made it read higher than the element at the same level outside. The element at position 9 was therefore discarded and each setting of temperature made with reference only to the elements which were attached directly to the bulb.

The temperature between the middle and the top shoulder was also examined in several experiments. The temperature at this position was found to be within 0.5° of the other two, with a tendency to be lower than these.

Further experiments showed that in addition to the possibility of vertical variation of temperature, there was a varia-

\* The system of numbering the positions of elements on the bulb is shown in fig. 1. The figure before the decimal point indicates the horizontal level, the figure after the decimal indicates the orientation around the bulb. For instance, an element in position 3.5 would be about half way between the top and middle and on the side of the bulb away from the front of the apparatus.

tion around the circumference of the bulb. This amounted in the worst case (at  $1450^{\circ}$ ) to a variation of  $1.3^{\circ}$  from the mean, four elements being used around the circumference to make the test. This variation seemed to be due either to unequal conductivity of the furnace material at different points or to the falling off of small portions of the furnace lining, leaving exposed places on the wire. Variations of this character are probably an unavoidable result of using a furnace where the heat supply is so near to the point where it

FIG. 2.

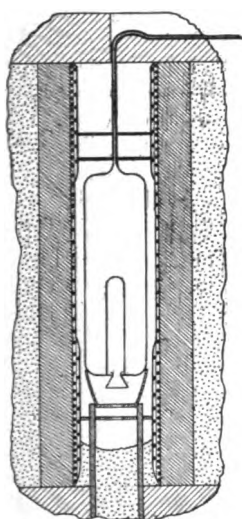


FIG. 3.

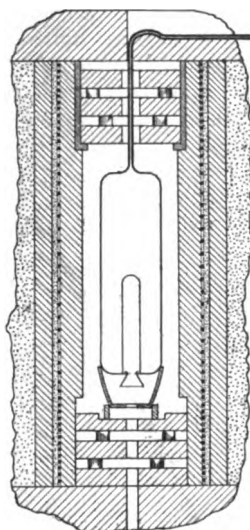


FIG. 2. Section of furnace and bulb showing the arrangement of coils and diaframs about the bulb which gave the most uniform temperature distribution in the measurement of both high and low temperatures. The supplementary end coils were independently heated and regulated.

FIG. 3. A special arrangement of the heating coil and diaframs designed to give a very uniform temperature distribution about the bulb. The coil was heavily ballasted inward with a good heat conductor and outward with a poor conductor. The heating coil was also divided into three sections which could be independently regulated. This furnace was used at the copper point only.

is measured, as is the case with the furnace which is wound on the inside. This form of winding is necessary, however, in order to reach the highest temperatures, so that absolute uniformity of temperature around the bulb had to be sacrificed to increased range of the instrument.

After this variation was discovered, measurements were always made with four elements at equal distances around the



circumference of the bulb and the mean of their readings was taken.

In order to be perfectly certain that no systematic error was being introduced by using this one form of furnace (fig. 2.) throughout, it was replaced temporarily by a furnace of platinum wire wound on the *outside* of a similar tube. In this way a heavy mass of good heat-conducting material was introduced between the source of heat and the bulb, with the expectation that a more uniform temperature might thereby be obtained in the inside space. The two types of furnace are shown in figs. 2 and 3.

A measurement at the copper point with the outside-wound furnace gave as the melting point of copper  $1082.6^{\circ}$ , which differs only  $0.4^{\circ}$  from  $1082.2^{\circ}$ , the mean of the results obtained at the same pressure with the other furnace, and is identical with the final mean of all the results, thus proving that no systematic error was to be feared from the inside-wound type of furnace. The horizontal uniformity obtained in the outside-wound furnace was better than that in the inside-wound, but the furnace was more difficult to regulate and to hold at a given temperature.

(b) *Constancy of Conditions.*—Several causes interfered with the establishment of a constant temperature for observation. The three heating currents required constant observation and readjustment with the gradual extension of the heated zone toward the outside of the furnace. This comes to equilibrium for a particular temperature after about half an hour, after which the bulb was held steady 15–30 minutes longer before readings of the pressure were taken. The temperature thus established could be relied upon to remain constant to within 1 to 3 microvolts ( $0.1^{\circ}$  to  $0.3^{\circ}$ ) during the course of the pressure measurements.

Above  $1100^{\circ}$  a noticeable leakage of current from the heating coil into the bulb and thermoelements frequently appeared. This may have been due in part to conductivity across the narrow air space between bulb and coil, but was probably chiefly due to accidental contact between the protecting tube of one of the thermoelements and the furnace wall. To obviate any uncertainty from this cause, it was found necessary to use alternating current for all temperatures above  $1100^{\circ}$ . This was less easy to regulate than the direct current from storage batteries, but by careful regulation of the voltage of the motor generator supplying the alternating current, equally satisfactory results were obtained.

The constancy and exactness of the temperature at  $0^{\circ}$  were beyond question. On several occasions pressure measurements at  $0^{\circ}$  were made at intervals of one-half to one hour and no

measurable difference found. Similarly, repacking the bulb in a fresh supply of ice gave exactly the same value.

*B. Definition of Temperature by Measurements of Pressure.*—The procedure in measuring the pressure,  $p$ , was as follows: First the three mercury thermometers on the manometer were read to determine the temperature of the mercury column and scale; then three to four settings of the barometer were made, alternating with measurements of the manometer. The mercury thermometers were read again at the close. During this interval the other observer made as many readings as possible of all the thermoelements.

Before the manometer was connected to the bulb, the point on the scale corresponding to the reference point of the manometer\* was determined once for all before the manometer was connected to the bulb, by connecting the two arms and raising the mercury to the point, as in a regular pressure measurement. Subsequent manometer readings were subtracted from this fixed level, and the resulting difference corrected for the temperature and calibration corrections of the scale and then reduced to  $0^\circ$ . The barometer reading was similarly corrected. The algebraic sum of the two gave the pressure  $p$ , in terms of a centimeter of mercury at  $0^\circ$  and at the latitude and elevation of the laboratory. Since the absolute value of the pressure does not enter into the gas thermometer formula, corrections for altitude and latitude are superfluous.

*Errors and Corrections in  $p$ .*—The level of the fixed reference point of the manometer varies with the temperature of the room because of the difference in expansion of the brass scale on the one hand and of the glass tube of the manometer which carries the fixed point on the other. This correction can be calculated from the expansion coefficients of the materials and amounts to  $0.04^{\text{mm}}$  per  $5^\circ$ . Its direction and amount were checked experimentally by determining the fixed point at two temperatures differing by about  $10^\circ$ , the room being open on a cold day for the one case, and then closed and heated for the other. The difference found was  $0.09^{\text{mm}}$ , and that calculated  $0.08^{\text{mm}}$ .

The lengths of the divisions of the brass scale were corrected for change of temperature by a formula determined for this scale at the Normal-Aichungs-Kommission, the absolute length of the scale having been determined at  $16^\circ$ . In addition, calibration corrections, determined for each millimeter of the scale, were applied. The total scale correction was always less than  $0.15^{\text{mm}}$ , hence the temperature measurement by the adjacent mercury thermometers was abundantly accurate for this purpose.

\* p. 100.

The length of the mercury column was reduced to  $0^\circ$  by the expansion coefficient given in the Landolt-Börnstein-Meyerhoffer Tabellen. This correction varied from 0 to about  $3.00^{\text{mm}}$ . As the mercury thermometers were calibrated and read to  $0.1^\circ$ , the uncertainty in this correction due to uncertainty in the room temperature may amount to  $0.05^{\text{mm}}$ . For the calibration the mercury thermometers were compared with a Richter standard thermometer calibrated at the Reichsanstalt.

The barometer reading was corrected to  $0^\circ$  by the Landolt-Börnstein-Meyerhoffer table for barometer with brass scale. Two Fuess barometers were used. Both had been tested by the Bureau of Standards; one had an absolute correction of  $0.06^{\text{mm}}$ , the other was exact. This was checked by direct comparison of the two. The variable error in the barometer is probably about the same as in the manometer reading ( $0.05^{\text{mm}}$ ). On a very windy day or during the approach of a storm, the barometer was too unsteady to permit satisfactory measurements to be made.

A further small correction to the barometer was necessary to allow for the weight of the air column between the cup of the barometer and the top of the mercury in the open manometer column. This correction was appreciable, amounting to  $0.16^{\text{mm}}$  in the extreme case.

To give some idea of the effect of these small corrections upon the final temperature measurement, it may be added that  $1.00^{\text{mm}}$  corresponds approximately to  $1^\circ$ .

To determine the corrected pressure,  $p$ , from the measured pressure,  $p'$  (see page 101), the volume of the unheated space,  $v_1$ , connecting the bulb with the manometer, must be known.\*

TABLE I. — *Unheated Space.*

Space	Volume, c.c.		Uncertainty		Max. effect at Cu. pt. of errors
	Before Apr. '09	After Apr. '09	of vol. of temp.		
Pt-Rh capillary, bulb to top furnace ( $v_1'$ )	0.055	0.055	0.002	100°	0.04°
Pt-Rh capillary, top to out- side furnace ( $v_1''$ )	0.086	0.086	0.003	50°	0.20°
Pt-Rh capillary to gold capillary	0.102	0.054	0.015	0.5°	0.20°
Gold capillary	0.094	0.066			
Pt capillary and Ni valve	0.025	0.025			
Space above meniscus	0.023	0.023			
Total	0.385	0.309			0.45°

\*See discussion of this correction, Day and Clement, loc. cit., p. 410.

This was calculated from the dimensions of the capillary. The figures are given in Table I. This volume was reduced in April, 1909, by bringing the manometer closer to the furnace, since the water jacket of the furnace cut off the heat so completely that there was no risk in bringing the manometer as close as possible (35<sup>cm</sup>). The volume  $v$ , was thereby reduced from 0.39<sup>cc</sup> to 0.31<sup>cc</sup>, and the ratio  $\frac{v}{V}$  from 0.00187 to 0.00150.

The volume,  $V$ , which enters into the correction term (see page 102) was determined by weighing the bulb empty, and filled with distilled water at a known temperature. A very accurate determination of this volume was not necessary, the important requirement being that the volume should not change during a run. A check on change of volume was obtained in the measurement of the value of  $p_0$ . The volume of the bulb at 0°, up to the base of the capillary stem, was found to be :

On 13 June, 1908 (new) . . . . .	205.74 <sup>cc</sup>
On 18 " " (after 1450°) . . . . .	205.75 <sup>cc</sup>
On 20 Apr., 1909 . . . . .	205.82 <sup>cc</sup>

The volume of the unheated space,  $v_1$ , was arbitrarily divided into three portions for the convenient determination of its average temperature,  $t_1$ . The first portion,  $v_1'$ , extended from the base of the stem to the top of the upper brick of the furnace (see fig. 2); the second portion,  $v_1''$ , included the capillary stem as far as the outside of the furnace; the third portion,  $v_1'''$ , extended to the surface of the mercury in the manometer and included all of that portion of the unheated space which remained at room temperature.

The temperatures of the portions  $v_1'$  and  $v_1''$  were determined by placing a thermoelement at different points along the stem during several of the runs. As this temperature does not need to be known accurately, a few measurements gave a sufficient indication of the distribution of temperature in the portion of the "unheated space" within the furnace.

A liberal estimate of the degree of uncertainty in the values of  $v$ , and  $t_1$  has been made and is included in Table I, together with the effect which such errors would have on the calculated temperature,  $t$ , at the copper point.

*Errors and Corrections in  $p_0'$ .*—The same instrumental corrections apply to  $p_0'$  as to  $p'$ , but their proportional magnitude is, of course, larger. The values of the uncertainty in  $t$  due to these small errors will be found in Table IV.

Changes in the value of  $p_0$  (the ice point) after heating to high temperatures have always been disturbing factors in gas thermometer measurements and have introduced uncertainties of a very intangible kind. This was especially true of the

porcelain bulbs formerly used, where both changes of volume and emission or absorption of gases by the walls occurred. The restoration of the platinum metals to favor as materials for the gas thermometer bulb has practically eliminated this uncertainty. During the present work small changes in the value of  $p$ , have frequently occurred after heating to a high temperature, which seem not to be due to any change in volume, for the determinations of the volume,  $V$ , given above (p. 109), show a total change after a year's work corresponding to less than  $0.1^{\text{mm}}$  in  $p$ . In the early part of the work, the passage through the bulb wall of hydrogen or some other gas produced by the reducing action of wood fiber in an asbestos board insulator within the furnace, was suspected as being the cause of irregularity, particularly in view of the fact that Holborn and Valentiner had difficulties from this cause. Further, it was several times observed that heating the furnace and bulb to a higher temperature than they had reached before, caused a slight increase in the value of  $p$ ,—whether due to some gas passing in from the outside, or coming out of the wall of the bulb, is not known. Air dried over calcium chloride was used outside of the bulb in the furnace enclosure throughout the work, and no indication was ever obtained of the passage of either oxygen or nitrogen through the wall of the bulb, since measurements at a given temperature (after the first heating to that temperature) gave the same value of  $p$ , within the error of measurement.

On one occasion an almost inappreciable leak in the manometer connection caused some uncertainty. All measurements affected by this error, when it was discovered, were rejected.

$\alpha$ .—Since the gas thermometer apparatus as arranged for high temperature measurements is not suited to a determination of the value of  $\alpha$  (the pressure coefficient of the gas from 0 to  $100^{\circ}$ ) with an accuracy comparable to that attained by Chappuis,\* the value of  $\alpha$  was treated as a constant. The figures used were:

$$\text{For } p_0 = 345 - 347^{\text{mm}}, \alpha = 3665.8 \times 10^{-4}$$

$$\text{For } p_0 = 217 - 221^{\text{mm}}, \alpha = 3664.0 \times 10^{-4}$$

A number of independent determinations of  $\alpha$  for different pressures were made by Day and Clement† with the platinum bulb, but they show no appreciable difference from those by Chappuis within the experimental error of the apparatus. The probable error in Chappuis' results is not great enough to affect the high temperature values.

\* Trav. Mem. Bur. Int., vi and xii, 1888 and 1902.

† Day and Clement, loc. cit., p. 442.

Pure nitrogen was used throughout as the thermometric gas.\* The storage tank was refilled several times so that not all the gas was from the same original supply; the filling of the bulb was also changed several times. The bulb was first completely evacuated and heated to a high temperature, after which the connections and bulb were rinsed out several times with the purified gas before the final filling.

*Expansion Coefficient of the Bulb. ( $\beta$ ).—*The substitution of a new alloy in place of the platinum-iridium made necessary a new determination of the expansion coefficient of the bulb material. The method of its determination and the comparator used for the purpose were fully described in the earlier article† and do not require to be repeated here.

Three additional precautions were taken in carrying out the measurements: The bar was increased in length to 0.5 meter, and in diameter to 6<sup>mm</sup>, in order to increase the sensitiveness of the determination and the uniformity of temperature along the bar respectively. In this case the bar was also made at the same time and from the same alloy as the bulb itself, and was therefore identical with it in composition.‡

In ruling the bar, the lines were spaced 0.2<sup>mm</sup> apart instead of 0.5<sup>mm</sup>, as in the previous investigation. This enabled a greater number of observations to be made within a narrow region than heretofore, and has thus made it possible for us to avoid the error from parallax described in the previous paper.§

The third precaution involved a slight change in the comparator itself, and was made at the suggestion of Chappuis. Our custom had been to verify the distance between the fixed hairs of the microscopes before and after each heating by measuring this distance in terms of a standard brass bar calibrated at the Bureau of Standards. The brass bar was then replaced by the platinum-iridium bar before the heating began, and the length of the latter was measured in terms of the initial distance between the fixed hairs, at intervals of 50° or

\* It was prepared by dropping a solution of 200 grams of sodium nitrite dissolved in 250 grams of water, into a warm solution containing 350 grams of ammonium sulphate and 200 of potassium chromate in 600 of water. It was passed through a mixture of potassium bichromate and sulphuric acid and stored over water. For use in the gas thermometer it was purified by passing through calcium chloride, hot copper gauze, potassium bichromate in sulphuric acid, 2 bottles potassium pyrogallate solution, sulphuric acid, calcium chloride and phosphorous pentoxide.

† Day and Clement, loc. cit., p. 425.

‡ The new bulb, as well as the bar, were made with the utmost care by Dr. Heraeus, of Hanau, Germany, for this investigation. We have had repeated occasion in the past to make public expression of our indebtedness to Dr. Heraeus for his interest and assistance in this work, and it is a pleasure to repeat this acknowledgment here.

§ Day and Clement, loc. cit., p. 435.

100° up to 1000°. This mode of procedure involved the assumption that the agreement of the measurements made before and after heating afforded adequate proof that no change had taken place *during* heating. The justification for this assumption lay in the fact that, (1) the furnace was completely water-jacketed to prevent any heat reaching the microscopes from the furnace; (2) suitable insulating material introduced between the observer and the microscopes cut off any disturbing influence from the near approach of the observer's body; (3) the microscopes themselves, and the carriages upon which they were mounted, were connected by carefully selected invar bars

FIG. 4.

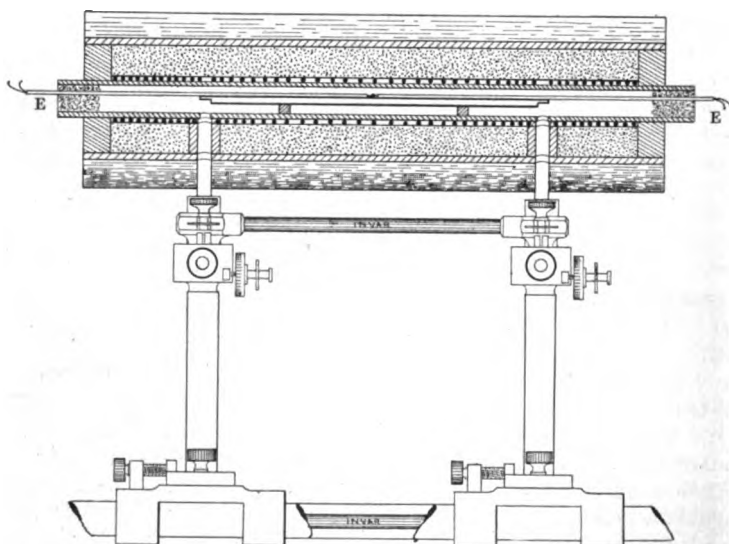


FIG. 4. Section through furnace showing bar, thermoelements (E, E) and microscopes in position. A section through the arrow is shown in fig. 5.

of negligible expansion coefficient, and, finally, (4) the faithful agreement of all the measurements before and after the many heatings left no reason for suspecting a variation.

Notwithstanding these conditions, it appeared to Chappuis that some positive proof should be offered that the distance between the cross-hairs remained unchanged while the heating was going on, inasmuch as all the measurements were made in terms of this distance. Accordingly, at his suggestion, it was arranged to retain a standard unheated bar in the field of the microscopes throughout the readings, so that the distance between the cross-hairs would be subject to check at any time

during the observations. The arrangement made for the purpose is very simple and effective, as can be seen from the neighboring diagrams (figs. 4 and 5). The last two series of measurements were made with this appliance, and the fixed distance was found to remain constant throughout the series to within  $0.003^{\text{mm}}$ , although on first setting up the apparatus a gradual adjustment of strain, amounting to  $0.012^{\text{mm}}$ , took place during the first two days.

The determination of  $\beta$  is subject to two errors; the first is uncertainty of temperature, the second occurs in the measure-

FIG. 5.

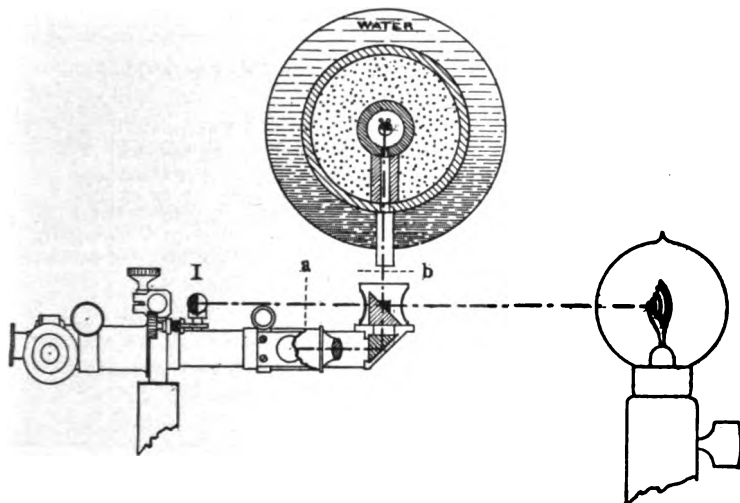


FIG. 5. A section through the furnace at one of the openings, showing the method of illumination of the heated bar and the standard cold bar (I) together with an arrangement for checking the distance apart of the cross hairs at each temperature. With a screen inserted at *a* only the hot bar is visible; with the screen at *b* only the cold bar.

ment of the change in length. It was impossible to wind the furnace ( $70^{\text{cm}}$  long and  $2^{\text{cm}}$  inside diameter, with two side openings) so as to give a perfectly uniform temperature along the bar; but as the furnace winding and consequent distribution of temperature were varied considerably for each run, the uncertainty from this cause was eliminated in the average of all the observations. The error in the temperature measurement itself was probably not over  $2^{\circ}$ , which would give an error of less than  $0.2$  per cent at the highest temperature. Two thermoelements with a common junction were used, one entering from each end of the furnace. This not only gave a second temperature reading in confirmation of the first, but



a positive check upon the appearance of contamination in the thermoelements.\*

With a half meter bar and a temperature interval extending from zero to 1400°, the total expansion amounts to about 7.8<sup>mm</sup>. The micrometers reading the expansion were read with an accuracy of 0.002<sup>mm</sup>.

There was some indication of a very small hysteresis in the expansion and contraction. Although the amount was not much greater than the experimental error, the measurements indicate that the bar was slightly shorter after heating than before, and that it gradually regained its original length.

The measurements at room temperature are given in Table II. The five measurements in this table which were made

TABLE II.—*Length of Platinum-Rhodium Bar.*

Date	Max. preceding temperature	Length at 0°	Date	Max. preceding temperature.	Length at 0°
1 July 1908	(New)	500.068	26 Sept. 1908	1150°	500.094
6 " "	900°	500.110*	1 Oct. " "	25°	500.119
9 " "	28°	500.105	6 " "	1300°	500.084†
13 " "	900°	500.098*	27 " "	900°	500.108*
17 Sept. " "	900°	500.108*	30 " "	1400°	500.096
19 " "	1200°	500.090	6 " 1909	28°	500.108
20 " "	28°	500.105	12 " "	22°	500.108*
22 " "	1200°	500.087	13 " "	1000°	500.109
24 " "	24°	500.096	15 " "	1400°	500.074†

\* After interval of 4-7 days.

† Bent, after heating beyond last temperature at which measurements were made.

within a few hours after the bar had cooled from a high temperature, excluding the two where the bar was bent, average 500.095; while the ten measurements (excluding the first) which were made two days or more after heating, average 500.106. The difference is only 0.002 per cent of the total length, or 0.12 per cent of the total expansion to 1500°, or about 0.7 per cent of the expansion to 300°. This effect is, therefore, probably responsible for the observed irregularities between 0° and 300°, at which temperature most of the measurements were begun.†

*C. Transference of Temperature by the Thermoelement.—*

The electromotive forces of the elements attached to the bulb were measured by a Wolff potentiometer. The standard of

\* Day and Clement, loc. cit., p. 419.

† Kammerlingh-Onnes (Konink. Ak. Wet. Amsterdam, Proc., x, 342, 1907) has found the same effect after cooling platinum to very low temperatures.

electromotive force used was the true volt, in terms of which the E.M.F. of the Clark cell is 1.4328 at 15°, and of the saturated cadmium cell used, 1.01918 volts at 25°.

Several small corrections are necessary in order to obtain the true E.M.F. of the thermoelement. The calibration corrections of the potentiometer (Reichsanstalt calibration) were all negligible except that for the fixed resistance to which the standard cell was attached. This correction amounted to 1.3 microvolts in 10,000. The correction for the change of resistance with temperature of the potentiometer was also negligible. The E.M.F. of the standard cell varies with the temperature; hence the temperature of the cell was read at each measurement and a small correction applied. The readings were correct at 21.5°. For a variation of 5° from this temperature the correction was 2.2 microvolts in 10,000 microvolts. The resistance of the contacts of the potentiometer, and the small E.M.F.'s existing at contact points in the circuit of the thermoelement, introduced another small error which was determined by placing the thermoelement in ice and reading the E.M.F. This correction varied for the different elements from -1 to +4 microvolts.

As a check upon the absolute value, a Weston standard cadmium cell (calibration by the Bureau of Standards) whose E.M.F. was read directly on the potentiometer, was compared with the saturated cell each day. The agreement of the corrected values was usually within 0.5 microvolt. As in the case of the pressure measurement, the absolute value of the E.M.F. is not of importance, since it is used only for transference from the fixed points to the gas thermometer; the above corrections were applied, however, to reduce the readings to a common standard.

The effect of contamination of the thermoelement wires in furnace readings was much greater than the above mentioned errors.\* Up to 1100° the contamination was not serious, but above that temperature the wires take up iridium together with some rhodium. It was hoped that the replacement of iridium in the bulb by rhodium, which is very much less volatile, would do away with this error, but there appeared still to be a very small percentage of iridium in the furnace wire, enough to affect the thermoelement wires appreciably, even though this furnace wire had been especially purified for this purpose.

Although the task became much longer and more laborious, it was thought wise to make an effort to avoid the error from contamination, even of this diminished magnitude, rather than to attempt to compromise with it by any scheme of approxi-

\* For a more thorough discussion of this effect, see Day and Clement, loc. cit., p. 419; and W. P. White, *Phys. Rev.*, xxiii, 449, 1906.

mate evaluation. Accordingly, after every exposure of sufficient length to endanger the thermoelectric readings, all the thermoelements were removed from the furnace and their wires tested for homogeneity. Where contamination was found, the contaminated portion of the wire was at once cut off. This is the only absolutely safe method of avoiding errors from this cause, for it amounts to the use of new thermoelements exclusively in all the determinations of temperature distribution within the furnace as well as for establishing the absolute temperature of the metal melting points.

A very simple method of testing the wires for contamination has been developed which consists in connecting the junction end of the wire to be tested, together with an uncontaminated wire, to the potentiometer and moving the free end of the standard wire along the wire to be tested, while heating the contact point of the two with a blast lamp.\* The variation of the E.M.F. produced at this junction indicates the degree of contamination of the wire; in the uncontaminated portion this E.M.F. is small and constant within 3 mv. The temperature obtained by the blast lamp flame is sufficiently constant for the purpose and lies between  $1460^{\circ}$  and  $1500^{\circ}$ .

The wires could be relied upon to give a constant E.M.F. within 2 mv. at  $1000^{\circ}$  over a length of at least  $50\text{ cm}$ , so that redeterminations of the fixed points were not necessary after cutting off each small portion of contaminated wire. Each test for contamination was continued over the  $50\text{ cm}$  of wire adjacent to the hot junction and so served as a test for the homogeneity of the new wire which replaced the portion cut off. In two cases a sudden change of E.M.F. along the unused wire amounting to about 10 mv. showed the probable presence of a junction point in the original sample from which the wire was drawn. Such a junction point was of course not introduced into the heated portion of the furnace.

In this connection, it should be pointed out that the relative weight to be given to the element inside the bulb, as compared with the outside elements, is greater at temperatures above  $1100^{\circ}$  than at temperatures below, for two reasons: (1) The temperature at the middle of the bulb is not so much influenced above  $1100^{\circ}$  by the temperature of the lower part of the furnace, as it is below  $1100^{\circ}$ ; (2) the outside elements are much more subject to contamination than the inside element by reason of the protection afforded by the intervening bulb walls against contaminating material from the heating coils. This is well shown by the data in Table VIII on the melting points of diopside, nickel and cobalt. In the first measurements of these temperatures, the elements were left on the bulb through

\* W. P. White, loc. cit.

several runs, in consequence of which the temperatures derived by the outside elements steadily increase through the series (i.e., the readings of the outside elements on the bulb steadily decreased), whereas the temperatures derived from the inside element are fairly constant. Its contamination was found to be less in amount and distributed over a region of more constant temperature.

For insulating the thermoelement wires from the bulb and furnace, capillary tubes, both of Marquardt porcelain and of silica glass, were employed. The Marquardt tubes are open to the objection that they are very porous and offer little protection against contamination. The silica glass capillaries protected the wires very much better, but at 1100° and above they devitrified rapidly and at the end of a measurement at 1400° or over fell from the wires in small fragments, so that the wires had to be taken off and reinsulated after a single run.

For the convenience of others who may confront similar problems, it may be added that such extreme precautions as cutting off the elements at the first sign of contamination are excessive for most purposes. The region of highest temperature, and therefore of most rapid contamination in a good furnace, is also a region of constant temperature. Contamination would therefore produce little effect upon the reading of the thermoelement until it had crept out into the colder parts of the furnace, which it will do slowly during long exposures. The distribution of the contamination in an aggravated case is shown in the accompanying table, which is arranged in such a way that not only the magnitude of the contamination but also its distribution with respect to the bulb is roughly shown. The electromotive forces are determined, as has been explained, by bringing successive points of the contaminated

		Before Heating. Microvolts	After Heating. Microvolts
	40 <sup>cm</sup>	-4	-4
	35	-6	-8
Outside of furnace	30	-8	-7
	25	-9	-6
	20	-6	-10
Bend of stem	15	-5	-3
	12	-5	+2
	10	-5	+9
	8	-5	+83
Shoulder of bulb	6	-5	+83
	4	-6	+41
	2	-6	+55
Middle of bulb	0	-8	----

wire into contact with an uncontaminated one in a blast flame (temperature, 1460–1500°), the cold junction being maintained constant at 0°. The absolute magnitude of the numbers in the column “before heating” represents the electromotive force between two uncontaminated platinum wires of (nominally) equal purity. Its constant value is a measure of the homogeneity of the new wire. Its departure from this constant value “after heating” is a measure of the contamination it has received. Slight irregularities are the result of variations in the blast flame temperature. Such observations merely serve to furnish information about the distribution and approximate amount of contamination received by the element, but do not of themselves provide the data to correct its reading in a particular furnace.

*Integration of Temperatures over the Bulb.*—By the method which has been already described (p. 104) the differences of temperature between the ends of the bulb and the middle were determined differentially by means of platinum wires attached to the bulb itself. Temperatures about the circumference were measured by separate thermoelements, as it was not practicable to measure these differences differentially because of the necessity of passing a platinum binding wire around the bulb to hold the four elements in position. A check on the accuracy of this differential method was obtained by using in one case a thermoelement at the top shoulder of the bulb and thus measuring the temperature at this point both directly and differentially by means of the platinum wire of this element. The two temperatures agreed within 0.8° when the deviation from the middle was 6°; when the temperatures at the middle and top were nearly equal, the two methods agreed to 0.1°.

Table III contains values of  $\frac{\Delta E}{\Delta t}$ , the rate of change of E.M.F. with temperature at various temperatures from 400° to 1500°, both for the 10 per cent rhodium alloy and for the 20 per cent

TABLE III.—Values of  $\frac{\Delta E}{\Delta t}$  for the alloys 90 Pt. 10 Rh. and 80 Pt. 20 Rh.

Temp.	90 Pt. 10 Rh.	80 Pt. 20 Rh.
400°	9.4	11.5
600°	10.1	12.8
800°	10.8	14.2
1000°	11.4	15.6
1200°	11.8	16.9
1400°	12.2	17.5
1500°	12.4	17.8

alloy of which the bulb was made. The data for the 20 per cent alloy (which need be only approximate) were obtained by two methods: (1) An element was made up by combining a platinum wire with the 20 per cent rhodium bar used for the expansion coefficient determination, and its readings compared directly with those of a 10 per cent rhodium element in the melting point furnace. (2) A platinum wire was connected from the stem of the gas thermometer bulb outside of the gas thermometer furnace to the ice box, and the E.M.F. determined against the standard platinum wire attached to the middle of the bulb. In both cases, the E.M.F. of the junction of platinum with the rhodium alloy at room temperature was applied as a correction.

In order to obtain the true E.M.F. corresponding to the temperature as measured by the pressure of the gas in the bulb, it is necessary to integrate the various readings over the surface of the bulb. The following arbitrary weights were given to the different positions of elements on the surface:

Top axis	(position 1)	5
Top shoulder	( " 2)	20
Middle	( " 4)	55
Bottom shoulder	( " 6)	15
Bottom axis	( " 7)	5

The elements on the axis at both top and bottom, although sometimes deviating rather widely from the others, have comparatively small weight, as they affect only a small portion of the total volume. The element at the lower shoulder of the bulb is given less weight than that at the top because of the smaller volume of the lower half, due to the presence of the reëntrant tube.

It was easy to show experimentally that it matters very little what these relative weights assigned to the different readings may be, since the total correction was usually small. In a number of cases, two different settings of the temperature distribution were made at each temperature, one in which the elements at the top and bottom shoulders of the bulb were made equal to the middle, and one in which the elements at top and bottom on the axis of the cylinder were made equal to the middle. The pressures corresponding to these two settings, reduced to the same reading of the standard element, are shown for several typical cases in the table below.

Date	Temp.	Pressure when 1, 4, and 7 were equal	Pressure when 2, 4, and 6 were equal
22 Jan. 1909	1082°	1038.82 <sup>mm</sup>	1038.64 <sup>mm</sup>
2 July 1909	1395°	1285.43	1285.17
17 Sept. 1909	1489°	1331.40	1330.63

It is evident that even without any correction for the different distribution in the two cases, the readings agreed within  $0.2-0.8^{\circ}\text{mm}$ , or about  $0.2-0.9^{\circ}$ , so that the variation between any two arbitrary sets of weights which might be given to the different readings must lie well within this limit.

*The Transfer to the Fixed Points.*—After the thermoelements are removed from the bulb, their E.M.F. at the fixed points must be determined by immersing them in melting or freezing metals or salts. The instrumental corrections to the readings so obtained were the same as in the case of the gas thermometer readings. The error due to contamination was also present above  $1100^{\circ}$ , just as in the gas thermometer furnace, and was a very disturbing factor in determining the melting points of nickel, cobalt and palladium. Its source, however, was not usually iridium vapor from the furnace or rhodium from the wire of the element, but was either vapor of the melting metal itself, or (when a hydrogen atmosphere was used) the products of reduction of silica. In the presence of hydrogen, silica rapidly deteriorates platinum wire by reduction and alloying, as has been shown in this laboratory by Shepherd,\* and elsewhere by several observers. The contamination can be partly prevented by the use of a glazed porcelain tube surrounding the thermoelement, instead of an unglazed magnesia tube; but an additional uncertainty is thereby introduced through the contamination of the melting metal by the melted glaze on the porcelain. For this reason nickel and cobalt did not prove to be as satisfactory fixed points as had been hoped, since it was necessary to melt them in an atmosphere of hydrogen. Palladium, however, can be melted in the open air and serious contamination by silicon thus be avoided, although the palladium itself gradually contaminates the wire.

Above  $1100^{\circ}$  it is better to make direct comparisons of all the elements with one or two whose fixed points have been determined, rather than to contaminate them all by a direct determination. For making these comparisons, the plan first used was to bring a crucible of molten silver to a constant temperature and insert the elements (protected by a glazed Marquardt porcelain tube) successively into the silver bath. There is an uncertainty, however, in these measurements of 2 to 3 mv., caused by small differences of temperature within the tube and to the slight cooling produced by introducing cold wires into the furnace. A better method is to join together the two platinum wires and the two alloy wires of the elements to be compared, and determine the small E.M.F.'s of each pair at several temperatures, from which the difference between the

\* This Journal (4), xxviii, 300, 1909.

elements at those temperatures can be obtained by algebraic addition. This method offers a great advantage in that the temperature need be only approximately constant and approximately known, since the differences in most cases amount to only a few microvolts. By this method the comparison can be very quickly made at 1500° in the blast-lamp flame, which, with a little care, can be made to give a temperature constant to 20°.

*D. Fixed Points.*—Considerable attention was given in the previous paper to the standard melting points which serve to establish the gas thermometer scale for general use. In particular, a study was made of the purity of the zinc, silver, gold, and copper used, and of the magnitude of the errors likely to arise with the ordinary metals obtainable in the market.\* During the present work, attention has been more particularly directed to the technic of melting point determination itself.†

All the metal melting points here described, except that of palladium, were made in an upright cylindrical furnace through which passed a glazed porcelain tube which could be tightly closed above and below and therefore permitted the atmosphere about the melting metal to be perfectly controlled. An effort was first made to accomplish this by placing the entire furnace inside a gas-tight bomb in which the atmosphere could be similarly varied, but the persistent retention of gases by the various clay insulating materials used about the furnace made this method slow, cumbersome, and very uncertain in its results. The only success which these bomb furnaces attained was to permit melting points to be measured in an approximate vacuum (about 1<sup>mm</sup> pressure). But it has since been found so much simpler to operate with a neutral or reducing atmosphere in the closed tube passing through the heated zone, that the vacuum furnace has not been used for this work.

The chief disadvantage in the use of a tube of this kind is its effect upon the temperature gradient along the furnace axis. More heat is diverted toward the ends of the furnace and the central constant temperature zone becomes shorter. It offers no difficulty except that greater care must be taken in locating the crucible within the constant temperature region.

The qualities desired in fixed thermometric points for establishing and reproducing a scale are:

(1) Exact reproducibility of the temperature in repeated determinations with the same charge of material and with a different charge independently obtained. This means that the metal or salt must be either perfectly pure or obtainable with a constant amount and kind of impurity.

\* E. T. Allen, in paper of Day and Clement, loc. cit., p. 454.

† See also W. P. White, Melting Point Determination and Melting Point Methods, this Journal (4), xxviii, 453 and 474, 1909.



(2) Independence of particular experimental arrangements. The melting point of a metal, for instance, must be sharp and definite enough so that with different kinds of furnaces and different rates of heating, the same temperature will be obtained.

(3) Convenience and safety of manipulation. A melting point which can only be obtained by the use of elaborate experimental arrangements is undesirable, even though it be reproducible and sharp. Furthermore, the substance must not injure the instrument to be calibrated.

(1) *Reproducibility*.—No extensive experiments have been made in the present work to test a large number of samples of different origin. It appeared sufficient to assure ourselves that all of the metals here used are obtainable in such degree of purity, or with such a constant amount of impurity, that the variations in their melting points are well within the limits of error in the scale itself. Waidner and Burgess\* have recently made comparisons of various samples of pure zinc, antimony, and copper, and have found no differences exceeding  $0.3^{\circ}$ .† Our experience has been the same. All of the metals in the present investigation are readily obtainable from the ordinary sources of supply. They have been carefully analyzed in this laboratory by Dr. E. T. Allen, and the results are given in section 6.

(2) *Independence of Experimental Conditions*.—A number of experiments were made to test the effect of different experimental arrangements on the points. Two different furnaces were tried, one 65<sup>mm</sup> inside diameter and 150<sup>mm</sup> long, the other 55<sup>mm</sup> inside diameter and 230<sup>mm</sup> long. The region of constant temperature in the second furnace was longer than in the first and accordingly there was a larger range in which the crucible could be moved about without affecting the temperature. This furnace was used for all work after March 6, 1909. The ultimate test was always the agreement between the melting and freezing points. Any serious disagreement of these two shows that some influence is entering from without.

The results of the study were briefly as follows: (1) The best dimensions for a charge of metal are about 25<sup>mm</sup> diameter by 45<sup>mm</sup> deep. (2) The thermoelement tube should be about 5<sup>mm</sup> above the bottom of the crucible. (3) There is a region within the furnace in which the melting and freezing points agree and are independent of the rate of heating or (within limits) of the depth of immersion of the thermoelement; it is necessary to find this position of the crucible by trial. With this position once determined, the temperature of the zinc, antimony, silver, gold, and copper points can be relied upon

\* Phys. Rev., xxviii, 467, 1909. Bull. Bur. Stds., vi, 149-230, 1909.

† In the case of antimony, this statement applies only to Kahlbaum's metal.

within  $0.2^{\circ}$ . With large charges and facilities for stirring the metal, Waidner and Burgess have found the zinc point to be reproducible in a given furnace, with a given sample, within less than  $0.1^{\circ}$ .

White\* showed that the temperatures of the two silicate points used for the present scale are reproducible within  $1.0^{\circ}$  independently of the dimensions of the furnace or the rate of heating. For a mineral melting point, the charge should be small (about 3 grams), the heat should approach the thermal junction from the side and not from the ends, and a position in the furnace should be found in which the melting point, determined by a bare thermoelement, does not vary with the rate of heating.

The possibility has been several times suggested that the temperature of the thermoelement inside of the tube might possibly be lower by a small constant amount than the temperature of the metal outside of the tube, and that this error might not be brought to light by such experiments as have been described. Several melting and freezing points of copper were, therefore, determined by enclosing the entire thermoelement wire in a thin capillary of silica glass which was slipped over the wire, bent double, and melted down upon the wire at the junction by heating in the oxyhydrogen flame. This was dipped directly into the molten copper to within  $5^{\text{mm}}$  of the bottom, so that there was practically no possibility that the temperature of the junction could be lowered by radiation or conduction upward. The melting point on element D obtained in this way was 10,473 microvolts as compared with 10,473 microvolts in the closed glazed tube. There appears to be no error from this cause.

*Convenience and Safety of Manipulation.*—Zinc and gold are the most convenient of manipulation, as they require no special atmosphere and the temperatures are easily reached. Antimony, silver, and copper require an atmosphere of carbon monoxide and are somewhat less convenient. More care needs to be taken with copper than with silver and antimony because of the considerable effect of a very small amount of oxide. Antimony, silver, gold, and copper were all melted in carbon monoxide, made by dropping formic acid into warm sulphuric acid, and purified by passage through sodium hydroxide, lead nitrate, and sulphuric acid. The lead nitrate was introduced to make certain that no trace of hydrogen sulphide, which might be formed if the acid became too dilute or too warm, could pass into the metal.

The two silicates (diopside and anorthite) and palladium were melted in air. The silicate points are very convenient to

\* Diopside and its Relations to Calcium and Magnesium Metasilicates, this Journal (4), xxvii, p. 5, 1909.

arrange and manipulate, provided the furnace is well insulated so that the temperature can be reached without difficulty. Palladium strains the platinum resistance furnace near to its limit of endurance on account of the high temperature, but has the great convenience of not requiring a reducing atmosphere. Special pains need to be taken, however, in this case, to protect the thermoelement from contamination.

Nickel and cobalt were melted in an atmosphere of hydrogen which was made by electrolysis in a large glass and earthenware generator, and purified by passage through potassium pyrogallate and sulphuric acid. Just before the thermoelement was introduced, the hydrogen was displaced by pure nitrogen drawn from a steel tank in which it was stored under pressure. The supply contained a trace of hydrogen and was, therefore, purified by passing over hot copper oxide and through calcium chloride and sulphuric acid. The extreme lightness of this gas compared with the outside air (especially when it is heated to  $1450^{\circ}$ ) makes necessary special precautions in order to keep out any trace of air. Furthermore, hydrogen always caused contamination in the thermoelement, which was not prevented even when the hydrogen was replaced for a short time during the melting by pure nitrogen. Nickel and cobalt are, therefore, not recommended for frequent use in the calibration of thermoelements, if the two points, diopside and palladium (or diopside and anorthite), give a sufficient calibration for the purpose in hand.

The apparatus used for the melting points of nickel and cobalt is shown in section in fig. 6. The top of the large porcelain tube (Marquardt, glazed outside only) was closed by a sliding cup of brass in which the thermoelement tube and two others for introducing hydrogen were fastened by heating the cup and pouring in molten solder. The porcelain tube extended far enough out of the furnace to keep the brass cup cool. A groove near the base of the cup carried a piece of asbestos cord which made a gas-tight joint with the porcelain tube and permitted the whole to be raised and lowered without moving the crucible or opening the top of the tube. Two diaphragms of Marquardt porcelain above the crucible also prevented any considerable radiation upward to the brass cup.

In zinc, antimony, silver, gold, and copper, the thermoelement was protected by a glazed Marquardt tube of 5<sup>mm</sup> inside and 8<sup>mm</sup> outside diameter. In the case of antimony, the tube was further protected by a thin tube of graphite which fitted into the cover of the crucible. With diopside and anorthite, some contamination from iridium in the furnace may take place, but can be largely prevented by surrounding the tube with pure platinum. A glazed Marquardt tube cannot be used in

this case, for the glaze flows readily at these temperatures and may make its way into the charge. With nickel and cobalt, glazed Marquardt tubes and also pure magnesia tubes of the same size were used, but neither protects the element from contamination. In palladium only the pure magnesia tubes were used.

Zinc, antimony, silver, gold, and copper were melted in graphite crucibles 27<sup>mm</sup> in diameter and 80<sup>mm</sup> deep inside, and 37<sup>mm</sup> in diameter and 100<sup>mm</sup> high outside. The charge of metal was from 45<sup>mm</sup> to 55<sup>mm</sup> deep. Diopside and anorthite were melted in small platinum crucibles 10<sup>mm</sup> in diameter and 18<sup>mm</sup> deep, as described and illustrated in the paper already referred to.\* Nickel was melted in an unglazed Marquardt porcelain crucible, lined with a paste consisting of about 90 per cent  $\text{Al}_2\text{O}_3$  and 10 per cent  $\text{MgO}$ ; and also in a Berlin "pure magnesia" crucible. The charge was about 25<sup>mm</sup> in diameter and 30<sup>mm</sup> deep. Cobalt could not be melted in the alumina lined crucible, as the metal penetrated through the lining and attacked the porcelain. It was, therefore, melted in a "pure magnesia" crucible made by the Königliche Porzellan Manufaktur. The material of these crucibles probably contains a small percentage of silica. Palladium was melted in a crucible made in this laboratory from a specially pure magnesia made by Baker and Adamson. The magnesia was first shrunk by heating to a temperature higher than that at which the crucible was to be used, and was then made into a paste with water and a little magnesium chloride, spun into form, and baked.

Particular details regarding each of the substances used will now be taken up in the order of their temperatures.†

\* W. P. White, this Journal (4), xxviii, 477, 1909.

† See, also, E. T. Allen, in paper of Day and Clement, loc. cit., p. 454.

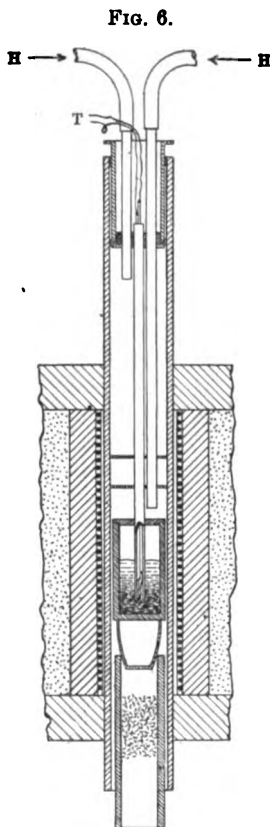


FIG. 6. The furnace in which the standard metal melting points were made, showing the position of the metal with respect to the coil, the thermoelement (T) and the arrangement (H) for maintaining a hydrogen or nitrogen atmosphere.

*Zinc*.—Two samples of “C. P. sticks” were used, both from Eimer and Amend. No appreciable difference could be observed between their melting points. Both melting and freezing points were sharp and measurable to a fraction of a microvolt. Successive readings did not differ by more than one microvolt. The charge was about 200 grams. The analysis has been published.\*

*Antimony*.—Two samples of metal were used, both from Kahlbaum, and no appreciable difference was found between their melting points. An analysis of the first sample is given in section 6. The charge weighed about 150 grams. The melting point is sharp and does not differ from the freezing point by more than one microvolt, provided the undercooling which always precedes solidification does not exceed  $15^{\circ}$ . If the metal is undercooled too far to give an accurate freezing point, the fact is easily recognized by observing that the thermoelement does not return to a sustained constant temperature, but merely rises to a maximum, then falls again. The amount of undercooling is greater the higher the metal has been heated above its melting point after the melting is complete.

*Silver*.—The charge weighed about 260 grams. Only one supply was used, a specially purified sample obtained from the Philadelphia Mint, of which an analysis is given in the previous paper.\* The melting and freezing points were sharp and agreed within one microvolt.

*Gold*.—A new charge of gold was used, weighing 350 grams. This was obtained from Dr. Eckfeldt of the Philadelphia Mint. No analysis was deemed necessary.\*

*Copper*.—The copper was obtained in the form known as “copper drops cooled in hydrogen” (Eimer and Amend). Only one supply was used. The melting and freezing points were not quite as sharp as was the case with silver, but always agreed within 1 microvolt. The temperature is very susceptible to a trace of oxide, which not only lowers the temperature appreciably but makes it more uncertain, so that if a little oxidation has taken place it is recognizable at once. Waidner and Burgess† found that the best commercial electrolytic copper showed an average difference of  $0.2^{\circ}$  in the melting point from the purified copper drops. Charge, about 210 grams.

*Diopside*.—Two samples of diopside were used, one from the preparation of Allen and White‡ and the other made up in 1909 by G. A. Rankin. No appreciable difference was found

\* E. T. Allen, in paper of Day and Clement, p. 454.

† Loc. cit., p. 469 (Phys. Rev.); p. 174 (Bull.).

‡ This Journal (4), xxvii, 1, 1909.

between the melting points. No freezing point can be obtained as the mineral undercools considerably. The charge used was 3 grams.

*Nickel.*—A sample of specially purified electrolytic nickel was obtained from Kahlbaum. The analysis showed less than 0.2 per cent total impurities. Care must be taken in the case of nickel that no oxide forms, as a fairly sharp break can be observed about 10° below the melting point, which may represent the eutectic of nickel and nickel oxide. This break disappeared when the nitrogen was replaced for a few minutes by hydrogen. This lower point may easily be mistaken for the melting point of the metal, and this mistake seems to have occurred in several of the published determinations of the melting point of nickel. Nickel absorbs hydrogen and possibly also nitrogen, and after cooling frequently showed excrescences and signs of "spitting" such as occur with silver in air.

*Cobalt.*—Kahlbaum's purest cobalt was used, containing less than 0.05 per cent total impurity. It was in the form of fine black powder, which was compressed into blocks for convenience in handling. The results obtained were not quite as satisfactory as with nickel on account of the higher temperature and more rapid contamination of the thermoelement. The absorption of gases seemed to be less than was the case with nickel.

Samples of Eimer and Amend's "98 to 99 per cent pure" nickel and cobalt were also tried. The difference between the two samples of nickel was not greater than the uncertainty in the melting point caused by contamination of the thermoelement. The "98-99 per cent pure" cobalt melted about 3.5° lower than the pure sample. Since the impurities in nickel are usually chiefly iron and cobalt, and those of cobalt are chiefly iron and nickel, and since the melting points of all three are close together, the melting points of the slightly impure metals can not be expected to lie far from those of the pure metals.

*Anorthite.*—Only one preparation of anorthite was used, made by G. A. Rankin 1909. The charge was about 3 grams. The melting point is not quite as sharp as that of diopside. Only the melting point can be obtained, as the mineral undercools considerably; it may even cool to glass without crystallization, in which case of course no melting point will be obtained on the following heating.

*Palladium.*—About 350 grams of pure palladium, in the form of sheet, was loaned to us by Dr. Heraeus. It melts and freezes quite sharply, making an excellent substance for a fixed thermometric point. The greatest uncertainty is caused by the vaporization of the metal and consequent contamination of the thermoelement wire. The charge used weighed 128-210 grams

In addition to the fixed points which have just been described, two other metal melting points, cadmium and aluminum, were incidentally determined. Only one measurement of the cadmium point was made on the gas thermometer, and this chiefly for the purpose of checking the extrapolation below the zinc point. The conditions of melting were the same as for zinc. The sample was obtained from Eimer and Amend, and its analysis has been given in a paper by Day and Allen.\* The charge weighed 215 grams.

A sample of pure aluminum obtained from the Aluminum Company of America was melted in a graphite crucible of the usual size in an atmosphere of carbon monoxide. On account of the sensitiveness of aluminum to silicon contamination, the tube carrying the thermoelement was also provided with a thin protecting cover of graphite so that the metal came in contact only with pure graphite. The freezing point was sharp and constant. The melting point was less sharp but lay within  $0.5^\circ$  of the freezing point.

The effect on the final temperature of all the errors and corrections which have been discussed in this section, is shown in summarized form in Table IV.

The figures of Table IV serve to emphasize the statements already made, that the greatest present uncertainty in the high temperature gas scale arises from the lack of uniformity in an air bath, which not only leads to uncertainty as to what is the true temperature of the gas in the bulb, but also to errors in the transference by the thermoelement. The next largest uncertainty, due to the limitations of the materials used for fixed points, is not directly chargeable to the gas thermometer. In this connection, considerably more work needs to be done on the high thermometric points, comparable in thoroughness to the work in low temperature thermometry of Richards, Dickinson, and others, on the sodium sulphate transition point.

#### 4. *Experimental Data and Calculated Results.*

*A. Expansion Coefficient.*—In Table V are given the experimental data on the expansion coefficients of the alloy 80 per cent platinum, 20 per cent rhodium. In the first column is given the date of the series, in the second and third columns the readings of the thermoelements at the middle of the bar, corrected for zero error and the temperature of the cadmium cell. The 12 other readings taken with each element at each temperature at different points along the bar cannot be given here, but the fourth and fifth columns contain the readings of the thermoelement corrected to represent the integrated tem-

\* Arthur L. Day and E. T. Allen, *Phys. Rev.*, xix, 180, 1904.

TABLE IV.—*Estimated Errors and their Effect on the Value of t.*

Quantity affected	Source of error	Amount of error		Effect on t	
		at 400°	at 1500°	at 400°	at 1500°
(A) Temperature of gas	Temperature differences over bulb surface	2 mv.	5 mv.	± 0·2°	± 0·4°
	Variability	0	1 mv.	0	± 0·1°
(B) $p_0$	Reference point	0·02 mm.	0·02 mm.	± 0·04°	± 0·15°
	Manometer setting	0·02 mm.	0·02 mm.	± 0·04°	± 0·15°
	Scale corrections	0·01 mm.	0·01 mm.	± 0·02°	± 0·07°
	Temperature of mercury	0·05 mm.	0·05 mm.	± 0·10°	± 0·38°
	Barometer setting	0·03 mm.	0·03 mm.	± 0·06°	± 0·23°
	Temperature of barometer	0·05 mm.	0·05 mm.	± 0·10°	± 0·38°
	Variations in $p_0$	0	0·05 mm.	0	0 to ± 0·3
	Reference point	0·02 mm.	0·02 mm.	± 0·02°	0
	Manometer setting	0·02 mm.	0·02 mm.	± 0·02°	0
	Scale corrections	0·02 mm.	0·02 mm.	± 0·02°	0
	Temperature of mercury	0·67 mm.	0·20 mm.	± 0·07°	± 0·05°
	Barometer setting	0·03 mm.	0·03 mm.	± 0·03°	± 0·01°
β	Barometer temperature	0·05 mm.	0·05 mm.	± 0·05°	± 0·01°
	Unheated } $v_1$	0·020 cc.	0·020 cc.	± 0·07°	± 0·5°
	space } $t_1$	0·5–50°	0·5–100°	± 0·01°	± 0·1°
	Temperature	1·0°	2·0°	± 0·02°	± 0·11°
	Expansion	0·005 mm.	0·008 mm.	± 0·02°	± 0·09
	Hysteresis in expansion	0·01 mm.	0·01 mm.	± 0·04°	± 0·10°
	Instrumental correction	1 mv.	2 mv.	± 0·1°	± 0·2°
	Contamination	0	0–12 mv.	0	0 to +1·0°
	Integration over bulb	3 mv.	12 mv.	± 0·3°	± 1·0°
	Instrumental corrections	1 mv.	2 mv.	± 0·1°	± 0·2°
(D) Fixed points	Contamination	0	0–10 mv.	0	0 to –1·0°
	Variation in given charge	Specific 1–10 mv.		Specific 0·1–1·0°	
	Variation between different charges	Specific 1–20 mv.		Specific 0·1–2·0°	



perature along the bar. For convenience, the integration was made in terms of microvolts instead of degrees. The sixth and seventh columns contain the temperatures corresponding

TABLE V.—*Observations of Expansion Coefficient,  $\beta$ .*

Date	Thermoelements				Temperature			Expansion from 0°	
	W	Z	W cor.	Z cor.	by W	by Z	Mean	mm on 500 mm	10 $\beta$
1908									
Sept. 21	2261	2251	2312	2298	301.4°	301.4°	301.4°	1.404	9.32
	3197	3187	3273	3258	404.6	405.4	405.0	1.912	9.44
	4169	4153	4257	4237	506.0	507.1	506.6	2.434	9.61
	5157	5140	5237	5212	608.9	605.1	604.5	2.950	9.76
	6197	6178	6286	6262	705.4	707.2	706.3	3.500	9.91
	7264	7238	7362	7333	806.2	807.8	807.0	4.064	10.07
	8361	8335	8457	8420	905.9	906.7	906.3	4.640	10.24
	9509	9470	9599	9552	1006.9	1006.8	1006.8	5.241	10.41
	10662	10611	10733	10675	1104.5	1103.4	1104.0	5.828	10.56
	11663	11896	12018	11921	1215.3	1210.2	1212.8	6.469	10.67
Sept. 25	1817	1801	1848	1831	248.7	248.4	248.6	1.154	9.28
	2756	2735	2791	2768	353.4	352.9	353.2	1.666	9.43
	3699	3674	3726	3702	451.8	452.0	451.9	2.158	9.55
	4686	4655	4691	4662	549.7	550.3	550.0	2.668	9.70
	5711	5679	5691	5660	648.2	649.2	648.7	3.191	9.84
	6820	6788	6772	6742	751.2	752.6	751.9	3.757	9.99
	7847	7813	7754	7720	842.2	848.2	842.7	4.262	10.11
	8980	8945	8845	8809	940.8	941.4	941.1	4.827	10.26
	10140	10102	9939	9901	1036.4	1037.0	1036.8	5.403	10.42
	11368	11327	11109	11063	1136.9	1136.4	1136.7	6.012	10.58
Oct. 3	2291	2272	2302	2283	300.3	299.8	300.1	1.384	9.22
	3228	3205	3250	3228	402.2	402.2	402.2	1.899	9.44
	4208	4181	4243	4215	504.6	504.9	504.8	2.432	9.63
	5205	5175	5247	5216	604.8	605.5	605.2	2.964	9.79
	6238	6206	6281	6249	704.9	705.9	705.4	3.511	9.95
	7297	7263	7342	7309	804.4	805.5	805.0	4.069	10.11
	8401	8365	8446	8408	904.9	905.6	905.3	4.644	10.26
	9536	9497	9576	9534	1004.9	1005.2	1005.1	5.231	10.41
	10675	10647	10710	10670	1102.6	1103.0	1102.8	5.830	10.57
	11884	11857	11926	11875	1207.5	1206.2	1206.8	6.466	10.71
Oct. 29	8419	8377	8366	8324	897.4	898.0	897.7	4.618	10.29
	9551	9507	9436	9392	992.6	992.8	992.7	5.169	10.41
	10706	10663	10539	10496	1088.0	1088.2	1088.1	5.752	10.57
	11884	11849	11786	11751	1195.6	1195.7	1195.7	6.401	10.70
	13137	13104	13134	13101	1309.9	1309.8	1309.9	7.154	10.92
1909	W	D	W cor.	D cor.	by W	by D			
Oct. 13	2304	2301	2235	2232	293.0	293.0	293.0	1.352	9.23
	6222	6217	6180	6175	695.2	695.9	695.6	3.452	9.92
	9501	9494	9493	9486	997.6	998.1	997.9	5.190	10.40
Oct. 14	9540	9536	9542	9544	1001.9	1003.1	1002.5	5.200	10.37
	10666	10663	10690	10691	1101.9	1102.5	1102.2	5.811	10.54
	11839	11836	11783	11783	1195.4	1195.7	1195.6	6.410	10.72
	12998	12993	13121	13120	1308.9	1308.6	1308.8	7.156	10.93
	14183	14170	14390	14372	1413.4	1411.6	1412.5	7.832	11.09

to the readings in columns 4 and 5, and the eighth column, the mean of these two temperatures. The micrometer readings are not given, but in column 9 will be found the expansions reduced to millimeters for that portion of the bar lying between the 0 and 50<sup>cm</sup> marks on the ends. Each of these represents the mean of eight settings at each end of the bar. In the last column are given the values of the mean expansion coefficient from 0°, calculated by dividing the expansion by the length at 0 and by the temperature.

For convenience of comparison, the values of  $\beta$  at the nearest round temperatures were interpolated linearly between the observations in each series, and the results are given in Table VI. Values interpolated between these values are given in parentheses.

TABLE VI.—*Values of  $10^6 \beta$  at Round Temperatures for the alloy 80 Pt, 20 Rh.*

Temp.	21 Sept. 1908	25 Sept. 1908	3 Oct. 1908	29 Oct. 1908	13 Oct. 1909	14 Oct. 1909	Mean
250		9.28					
300	9.31	(9.36)	9.22		9.24		9.28
350	(9.37)	9.43	(9.33)		(9.33)		9.36
400	9.43	(9.49)	9.44		(9.41)		9.44
450	(9.52)	9.55	(9.53)		(9.50)		9.52
500	9.60	(9.62)	9.62		(9.58)		9.61
550	(9.67)	9.70	(9.71)		(9.67)		9.69
600	9.75	(9.77)	9.79		(9.76)		9.77
650	(9.83)	9.84	(9.86)		(9.84)		9.84
700	9.90	(9.92)	9.94		9.93		9.92
750	(9.98)	9.99	(10.02)		(10.01)		10.00
800	10.06	10.06	10.10		(10.09)		10.08
850	(10.14)	10.12	(10.17)		(10.16)		10.15
900	10.23	(10.20)	10.25	10.29	(10.24)		10.24
950	(10.31)	10.27	(10.32)	(10.36)	(10.32)		10.32
1000	10.40	(10.36)	10.40	10.42	10.40	10.37	10.39
1050	(10.47)	10.44	(10.48)	(10.50)		(10.45)	10.47
1100	10.55	(10.52)	10.57	10.59		10.54	10.55
1150	(10.60)	10.60	(10.64)	(10.65)		(10.63)	10.62
1200	10.65	(10.67)	10.71	10.71		10.73	10.69
1250				(10.81)		(10.82)	10.81
1300				10.90		10.92	10.91
1350				(10.99)		(10.99)	10.99
1400						11.07	11.07
1450							(11.15)
1500							(11.23)

The table shows that the percentage error at 300° is greater than that at 1200° and above, probably on account of the larger effect of the hysteresis in the expansion and contraction, already discussed on page 114. The agreement of the results is very satisfactory, particularly in view of the fact that each

series represents an entirely different curve of temperature variation along the bar. In some cases the temperatures at the ends were lower than at the middle, in others higher than at the middle, and in one series one end was higher and the other lower. The mean of all, therefore, probably eliminates any error which might arise from variation of temperature along the bar.

The results are represented within the limits of error by the straight line equation :

$$10^{\circ}\beta = 8.79 + 0.00161t.$$

This may be compared here with the expansion coefficients between 300° and 1000° determined by the authors for the 10 per cent iridium alloy,\* and of Holborn and Day† for the 20 per cent iridium alloy and for pure platinum :

$$80 \text{ Pt. } 20 \text{ Ir. } 10^{\circ}\beta = 8.20 + 0.00142t$$

$$90 \text{ Pt. } 10 \text{ Ir. } 10^{\circ}\beta = 8.84 + 0.00131t$$

$$\text{Pt. } 10^{\circ}\beta = 8.87 + 0.00132t.$$

*B. Gas Thermometer Data and Fixed Points.*—In Table VII are given the observed gas thermometer data.‡ In the first column is the date of the measurement. The measurements are numbered chronologically in the second column for convenience of reference. In the third column is the measured pressure,  $p'$  (or  $p_o'$ ) in millimeters of mercury at 0°, corrected as described on pages 107 and 108. The application of the correction for unheated space (see p. 108) gives the pressure  $p$  (or  $p_o$ ) which is found in the fourth column. In the fifth column is the value of the temperature,  $t$ , calculated by formula (5) on page 101. In column 6 are given the readings of the standard thermoelements in microvolts, and in column 7 the positions of these elements on the bulb; for the significance of these figures see fig. 1 and note on page 104. In the last column are given the other elements which were used on the bulb, together with their positions designated in the same way. The italicized letters represent single platinum wires instead of thermoelements.

A few measurements in which the value of  $p_o$  changed by more than 0.1 per cent have been omitted; their position is shown by the absence of their corresponding serial numbers.

\* Published in paper of Day and Clement, loc. cit, pp. 425-441.

† This Journal (4), xi, 374, 1901.

‡ For the measurements in the table, seven furnaces were employed, using three supplies of platinum wire of about 400 grams each. One of these furnaces was wound on the outside, the other six on the inside of the tube. It was possible to rewind the wire at least once after the furnace had burned out. Failure always occurred several cms. away from the bulb in the end portions of the furnace, which, in order to secure uniformity of temperature over the bulb, had to be considerably superheated. Only one measurement was made at the palladium point, as this one rendered the furnace unfit for further use; the conditions of this measurement, were, however, perfect.

**TABLE VII—Observed Gas-Thermometer Data.**

Date	No.	$p'$ (or $p_0$ )	$p$ (or $p_0$ )	$t$	Standard Elements	Position	Other elements and positions
1908							
GAS FILLING No. 1							
30 Nov.	1	217·65	217·63	0°	-----		
"	2	1037·77	1042·72	1079·87	W10448 } X 10491 }	4 8	Z (1), S (9)
1 Dec.	3	217·45	217·43	0	-----		
2 Dec.	5	217·10	217·08	0	-----		
3 Dec.	6	948·81	952·84	960·59	W 9061 } X 9100 }	4 8	Z (1), S (9)
4 Dec.	7	217·12	217·10	0	-----		
16 Dec.	8	217·08	217·06	0	-----		
17 Dec.	9	1038·50	1043·48	1083·61	W10483 } X 10555 }	4 8	Z (1), S (9)
18 Dec.	10	217·18	217·16	0	-----		
19 Dec.	11	1038·57	1043·56	1083·77	W10478 } X 10512 }	4 8	Z (1), S (9)
21 Dec.	12	217·06	217·04	0	-----		
23 Dec.	15	217·49	217·47	0	-----		
24 Dec.	16	1242·38	1249·71	1365·71	A 13866 } X ----- }	4 8	Y (1), S (9)
28 Dec. 1909	17	217·57	217·55	0	-----		
22 Jan.	18	1039·78	1044·74	1082·84	A 10502 } Y 10612 }	4 8	Z (9), B (1·3) W (2·3), S (6·7) X (7·8)
"	19	1038·82	1043·79	1081·87	A 10506 } Y 10584 }	4 8	Do.
"	20	1037·85	1042·83	1080·89	A 10498 } Y 10555 }	4 8	Do.
23 Jan.	21	217·36	217·34	0	-----		
25 Jan.	22	543·01	544·07	418·40	A 3414 } Y 3436 }	4·5 8	Do.
"	23	542·27	543·82	417·43	A 3408 } Y 3435 }	4·5 8	Do.
26 Jan.	24	703·78	705·61	629·80	A 5510 } Y 5550 }	4·5 8	Do.
"	25	702·64	704·67	628·84	A 5501 } Y 5529 }	4·5 8	Do.
"	26	949·56	953·68	960·22	A 9090 } Y 9159 }	4·5 8	Do.
"	27	948·15	952·23	958·41	A 9075 } Y 9119 }	4·5 8	Do.
"	28	1039·03	1044·05	1088·01	A 10515 } Y 10593 }	4·5 8	Do.
"	29	1037·92	1042·93	1081·56	A 10505 } Y 10556 }	4·5 8	Do.
27 Jan.	30	217·33	217·31	0°	-----		
28 Jan.	31	542·87	543·92	418·30	A 3410 } Y 3436 }	4·5 8	Do.
"	32	542·07	543·11	417·25	A 3404 } Y 3425 }	4·5 8	Do.
"	33	704·06	706·07	630·21	A 5514 } Y 5553 }	4·5 8	Do.

TABLE VII—(Continued)

Date	No.	$p'$ (or $p_0'$ )	$p$ (or $p_0$ )	$t$	Standard Elements	Position	Other elements and positions
28 Jan.	34	703·35	705·37	629·31	A 5510 Y 5537	4·5 8	Z (9), B (1·3), W (2·3), S (6·7) X (7·3)
"	35	948·96	953·05	959·46	A 9087 Y 9142	4·5 8	Do.
"	36	949·86	953·97	960·69	A 9098 Y 9163	4·5 8	Do.
"	37	1038·50	1043·57	1082·23	A 10511 Y 10576	4·5 8	Do.
"	38	1038·99	1044·06	1082·90	A 10512 Y 10585	4·5 8	Do.
"	39	1039·61	1044·68	1083·68	A 10509 Y 10617	4·5 8	Do.
29 Jan.	40	217·37	217·35	0°	----	----	----
"	41	949·32	953·38	959·78	A 9086 Y 9156	4·5 8	Do.
"	42	948·58	952·66	958·81	A 9085 Y 9131	4·5 8	Do.
"	43	1039·29	1044·34	1083·15	A 10515 Y 10595	4·5 8	Do.
"	44	1038·49	1043·56	1082·09	A 10511 Y 10568	4·5 8	Do.
"	45	1039·63	1044·71	1083·58	A 10508 Y 10617	4·5 8	Do.
30 Jan.	46	217·39	217·37	0	----	----	----
GAS FILLING No. 2							
18 Feb.	47	346·74	346·70	0	----	----	----
22 Feb.	48	346·78	346·74	0	----	----	----
23 Feb.	49	745·09	746·19	319·55	A 2487 D 2483 Z 2462	4·5 4·5 8	W (1·3), B (2·2), X (6·2), S (7·3), Y (12)
"	50	866·47	868·15	418·40	A 3414 D 3406 Z 3385	4·5 4·5 8	Do.
"	51	995·97	998·38	524·71	A 4451 D 4439 Z 4413	4·5 4·5 8	Do.
"	52	1122·39	1125·61	629·37	A 5510 D 5495 Z 5463	4·5 4·5 8	Do.
24 Feb.	53	346·67	346·63	0	----	----	----
26 Feb.	59	346·24	346·20	0	----	----	----
"	60	1657·03	1665·07	1083·17	A 10508 D 10473 Z 10422	4·5 4·5 8	W (3·3), B (2·2), X (6·2), S (7·2), Y (12)
27 Feb.	61	346·45	346·41	0	----	----	----
1 Mar.	62	1338·84	1394·13	853·76	A 7895 D 7869 Z 7829	4·5 4·5 8	B (3·2), W (2·3), X (6·2), S (7·2), Y (12)
"	63	1513·67	1520·20	960·29	A 9086 D 9055 Z 9010	4·5 4·5 8	Do.
"	64	1632·03	1639·78	1062·15	A 10265 D 10229 Z 10178	4·5 4·5 8	Do.

TABLE VII—(Continued)

Date	No.	$p'$ (or $p_0'$ )	$p$ (or $p_0$ )	$t$	Standard Elements	Position	Other elements and positions
1 Mar.	65	1655.77	1663.81	1082.84	A 10511 D 10474 Z 10420	4.5 4.5 8	B (3.2), W (3.3), X (6.2), S (7.2), Y (12)
2 Mar.	66	346.20	346.17	0	-----		
3 Mar.	67	1386.28	1391.55	852.44	A 7885 D 7861 Z 7820	4.5 4.5 8	W (3.8), B (2.2) X (6.2), S (7.2) Z (8), Y (12)
"	68	1511.95	1518.48	959.81	A 9088 D 9059 Z 9018	4.5 4.5 8	Do.
"	69	1628.71	1636.46	1060.24	A 10257 D 10221 Z 10169	4.5 4.5 8	Do.
"	70	1654.46	1662.50	1082.73	A 10511 D 10478 Z 10444	4.5 4.5 8	Do.
5 Mar.	71	345.98	345.94	0	-----		
GAS FILLING No. 3							
4 June	72	345.31	345.27	0	A 3403 E 3419	4.1 4.3	Y (1), a (2.4), b (6.4)
"	73	861.67	862.94	417.07	F 3414 G 3416 Z 3370	4.5 4.7 8	
"	74	1118.50	1120.83	629.11	A 5516 E 5535 F 5528 G 5529 Z 5461	4.1 4.3 4.5 4.7 8	Do.
5 June	75	345.31	345.27	0	-----		
"	76	1510.50	1515.27	959.77	A 9090 E 9114 F 9099 G 9108 Z 9002	4.1 4.3 4.5 4.7 8	Do.
"	77	1628.08	1633.64	1060.53	A 10258 B 10285 F 10266 G 10279 Z 10161	4.1 4.3 4.5 4.7 8	Do.
"	78	1652.36	1658.10	1081.28	A 10503 E 10529 F 10510 G 10523 Z 10404	4.1 4.3 4.5 4.7 8	Do.
7 June	79	345.50	345.46	0	-----		
10 June	80	345.52	345.48	0	-----		
18 June	81	1512.96	1517.69	961.21	F 9129 E 9128 A 9080 G 9122 Z 9015	4.1 4.3 4.5 4.7 8	a (1), b (2.4), c (6.4), e (7.3)
"	82	1630.94	1636.53	1062.53	F 10299 E 10300 A 10252 G 10292 Z 10181	4.1 4.3 4.5 4.7 8	Do.

TABLE VII—(Continued)

Date	No.	$p'(\text{or } p_0')$	$p(\text{or } p_0)$	$t$	Standard Elements	Position	Other elements and positions
18 June	83	1653.61	1659.37	1082.14	F 10534 E 10534 A 10487 G 10526 Z 10403	4.1 4.3 4.5 4.7 8	$a(1), b(2.4)$ $c(6.4), e(7.3)$
					F 10536 E 10534	4.1 4.3	Do.
"	84	1654.51	1660.27	1082.91	A 10485 G 10525 Z 10426	4.5 4.7 8	
19 June	85	345.51	345.47	0	----		
GAS FILLING No. 3a							
19 June	86	219.73	219.71	0	F 5520 E 5520	4.1 4.3	$a(1), e(2.3)$ $c(6.3), f(7.3)$
"	87	710.34	711.83	627.61	A 5484 G 5516 Z 5437	4.5 4.7 8	
					F 9139 E 9136	4.1 4.3	Do.
"	88	962.21	965.23	961.71	A 9089 G 9131 Z 9036	4.5 4.7 8	
					F 10540 E 10538	4.1 4.3	Do.
"	89	1051.74	1055.41	1082.75	A 10490 G 10531 Z 10428	4.5 4.7 8	
21 June	90	219.74	219.72	0	----		
22 June	92	220.65	220.63	0	----		
24 June	93	220.62	220.59	0	----		
25 June	95	220.56	220.53	0	----		
					H 14251 E 14227	4.1 4.3	Do.
2 July	96	1283.36	1288.82	1391.97	F 14222 G 14245 Z 14121	4.5 4.7 8	
					H 14262 E 14247	4.1 4.3	Do.
"	97	1285.43	1290.89	1394.89	F 14241 G 14274 Z 14156	4.5 4.7 8	
3 July	98	221.02	220.99	0	----		
					H 14213 E 14214	4.1 4.3	Do.
"	99	1281.97	1287.45	1393.34	F 14196 G 14216 Z 14099	4.5 4.7 8	
					H 14264 E 14242	4.1 4.3	Do.
"	100	1284.05	1289.54	1396.17	F 14235 G 14259 Z 14156	4.5 4.7 8	
6 July	101	220.62	220.60	0	----		

TABLE VII—(Continued)

Date	No.	$p'$ (or $p_0'$ )	$p$ (or $p_0$ )	$t$	Standard Elements	Position	Other elements and positions
GAS FILLING No. 4							
8 July	102	216·81	216·79	0	H 14235	4·1	$a$ (1), $e$ (2·3) $c$ (6·3), $f$ (7·3)
					E 14216	4·3	
"	103	1261·35	1266·80	1391·15	F 14209	4·5	
					G 14232	4·7	
					Z 14124	8	
					H 14249	4·1	Do.
					E 14229	4·3	
"	104	1263·13	1268·59	1393·55	F 14199	4·5	
					G 14236	4·7	
					Z 14155	8	
9 July	105	217·36	217·33	0	H 14251	4·1	Do.
					E 14236	4·3	
"	106	1261·71	1267·15	1391·64	F 14233	4·5	
					G 14241	4·7	Do.
					Z 14123	8	
					H 14240	4·1	
					E 14236	4·3	
"	107	1263·01	1268·46	1393·44	F 14225	4·5	
					G 14233	4·7	
					Z 14152	0	
10 July	108	217·35	217·33	0	H 15019	4·1	Do.
					E 15020	4·3	
"	109	1306·60	1312·52	1455·37	F	4·5	
					G	4·7	Do.
					Z 14903	8	
12 July	110	217·36	217·34	0	H 14978	4·1	
					E 14980	4·3	
"	111	1305·53	1311·35	1453·52	F	4·5	
					G	4·7	Do.
					Z 14867	8	
					H 14980	4·1	
					E 14960	4·3	
"	112	1305·46	1311·28	1453·31	F 14947	4·5	
					G	4·7	
					Z 14872	8	
13 July	113	217·40	217·38	0	H	4·1	$a$ (1), $c$ (2·3) $e$ (6·7), $f$ (7·3)
10 Sept.	114	217·38	217·36	0	E 15389	4·3	
					F 15374	4·5	
					G	4·7	
					A 15357	8	
11 Sept.	115	1328·68	1334·79	1484·70	H	4·1	Do.
					E 15411	4·3	
					F 15417	4·5	
					G 15418	4·7	
					A 15421	8	
13 Sept.	117	217·62	217·60	0			



TABLE VII—(Continued)

Date	No.	$p'$ (or $p_0'$ )	$p$ (or $p_0$ )	$t$	Standard Elements	Position	Other elements and positions
15 Sept.	118	1329·92	1336·08	1487·36	H .....	4·1	$a$ (1), $c$ (2·3) $e$ (6·7) $f$ (7·3)
					E 15391	4·3	
					F 15389	4·5	
					G 15399	4·7	
					A 15382	8	
16 Sept.	119	217·51	217·49	0	H .....	4·1	Do.
					E 15386	4·3	
					F 15376	4·5	
17 Sept.	120	1329·68	1335·78	1486·95	G 15368	4·7	Do.
					A 15379	8	
					H .....	4·1	
					E 15397	4·3	
					F 15396	4·5	
“	121	1331·40	1337·51	1489·34	G 15389	4·7	Do.
					A 15412	8	
					H .....	4·1	
18 Sept.	122	217·52	217·50	0	E 14991	4·3	Do.
					F 14996	4·5	
					G 14957	4·7	
21 Sept.	123	1306·75	1312·72	1454·83	A 14982	8	Do.
					H .....	4·1	
					E 14979	4·3	
					F 14984	4·5	
					G 14952	4·7	
“	124	1307·28	1313·25	1455·60	A 14996	8	Do.
					H .....	4·1	
					E 10618	4·3	
22 Sept.	125	217·45	217·43	0	F 10622	4·5	$a$ (1·5), J (2·4) $c$ (6·2), $e$ (7·2)
					G 10616	4·7	
					C 10567	8	
27 Nov.*	126	1045·80	1049·49	1090·59	H 12002	4·1	Do.
					E 12006	4·3	
					F 12003	4·5	
					G 12010	4·7	
					C 11914	8	
29 Nov.	127	217·28	217·26	0	H 13106	4·1	Do.
					E 13112	4·3	
					F 13107	4·5	
					G 13115	4·7	
					C 13007	8	
9 Dec.	128	1129·52	1133·91	1206·63	H 14246	4·1	Do.
					E 14250	4·3	
					F 14248	4·5	
					G 14256	4·7	
					C 14146	8	
“	129	1194·81	1199·74	1298·01	H 11940	4·1	$a$ (1), J (2·3), $c$ (6·2), $e$ (7·1)
					E 11946	4·3	
					F 11951	4·5	
					G 11949	4·7	
					C 11887	8	
10 Dec.	131	217·30	217·28	0	H 11940	4·1	$a$ (1), J (2·3), $c$ (6·2), $e$ (7·1)
					E 11946	4·3	
					F 11951	4·5	
20 Dec.	132	1125·92	1130·29	1201·50	G 11949	4·7	$a$ (1), J (2·3), $c$ (6·2), $e$ (7·1)
					C 11887	8	
					H 11940	4·1	

\* Outside-wound furnace. See page 106.

TABLE VII—(Concluded)

Date	No.	$p'$ (or $p_0'$ )	$p$ (or $p_0$ )	$t$	Standard Elements	Position	Other elements and positions
20 Dec.	133	1302.40	1308.33	1450.03	H 14950	4.1	$\alpha$ (1), J (2.3) $c$ (6.2), $e$ (7.1)
					E 14958	4.3	
					F 14962	4.5	
					G 14955	4.7	Do.
					C 14882	8	
					H 16156	4.1	
					E 16160	4.3	
"	134	1372.16	1378.78	1550.15	F 16170	4.5	
					G 16148	4.7	
					C 16075	8	
21 Dec.	135	217.29	217.27	0	----		

(Continued from p. 132.)

The melting and freezing points of the metals and salts, measured with the various thermoelements used during the investigation, as well as the frequent comparisons of thermoelements with each other, are too numerous to be published here, especially as they are practically all summarized in Table VIII.

Table VIII contains the final temperature of each thermometric point studied. In the first column is the number of the experiment corresponding to that in Table VII. In the second column is the correction in degrees to be applied to each of the thermoelement readings on the *outside* of the bulb, integrated from the readings of the auxiliary elements as described on page 119; in the third column is given the corresponding correction in microvolts. In the fourth column are the readings of the standard elements on the *outside* of the bulb, corrected as above mentioned. In the fifth column are the readings of the same thermoelements at the fixed point in question, as obtained in the melting or freezing of metal or salt; these figures usually represent the mean of a considerable number of determinations.

In the sixth and seventh columns are the corresponding figures for the element *inside* of the bulb. In this case, however, no correction has been applied to the reading of the element, since, being located practically at the center of the bulb, it might be expected to represent the mean temperature of the entire volume of the bulb.

In the eighth and ninth columns are the temperatures of the fixed points derived from the preceding four columns. In the last column is given the weight assigned to each measurement. In assigning these weights the number of standard thermoelements used, the amount of variation in  $p_0$ , and other incidental variables were taken into consideration.

As has been pointed out on page 116, the relative weights to be assigned to the inside and outside elements are different at

different temperatures; (1) on account of the difference in contamination, and (2) on account of the fact that the inside element is subject to the influence of conduction and radiation from below. The weights assigned were as follows:

Temperatures	Outside Element	Inside Element
400–1100°	3	1
1100–1300°	2	1
1300–1550°	1	1

The final weighted mean of the inside and outside elements is given at the head of each section of the table.

In the last section of the table are given various points which were determined to aid in interpolating between the fixed points by means of the thermoelement.

The only comment which need be made here on the data in Table VIII concerns the figures given under the heading "copper point." In this section of the table, the values derived at the two different initial pressures (217–221<sup>mm</sup> and 346–347<sup>mm</sup>) are quoted separately in order to bring out the fact that the difference between the temperatures obtained from these two pressures is less than the experimental error. In the other sections of the table the data obtained at the two pressures are not separately arranged. Above the copper point only the low pressure was used, as the high pressure would have exceeded the range of the manometer.

The significance of the comparison between the inside-and outside-wound furnaces, which appears in the first half of the section on the copper point, has been commented on elsewhere (see p. 106).

##### 5. Interpolation Between the Fixed Points.

The preparation of formulae to represent the relation between the temperature defined by the gas thermometer and the electromotive force of a thermoelement has always been a cause of considerable dissatisfaction, both to the maker and the user. The chief reason for this is perhaps the fact that the formulae used have been applicable only to limited portions of the curve and have therefore given no suggestion of physical significance. In the Reichsanstalt publication\* the data extended from 300° to 1100° and included several good fixed points (melting points of pure metals) between which no interpolation, however rough, could go far astray. Accordingly, in so far as interpolation was concerned, but little attention required to be given to the formulation of this relation. It was sufficient that a simple formula of the form

$$E = -a + bt + ct^2$$

could be made to represent the observations between 300° and 1100° within the limits of the errors of observation.

\* Holborn and Day, 1900, loc. cit.

TABLE VIII—Temperatures of the Fixed Points.

Exp. No.	Integrated correction to outside elements Degr's M.V.		Standard Elements				Temperature		Weight
			Outside Corrected	Fixed Pt.	Inside Uncor-rected	Fixed Pt.	By Outside Element	By Inside Element	
Zinc Point. 418.2°									
22	0.0°	0	A 8414	8411	Y 8436	8436	418.1°	418.4°	2
23	-0.3	-3	A 8405	8410.5	Y 8445	8435	418.0	418.4	2
31	0.0	0	A 8410	8410.5	Y 8436	8435	418.3	418.2	2
32	-0.2	-2	A 8402	8410	Y 8425	8434	418.0	418.1	2
50	-0.1	-0.5	A 8413	8411			418.2		
			D 8405.5	8406	Z 8384.5	8382	418.4		
							418.3	418.2	3
73	-0.2	-2	A 8401	8418.5			418.4		
			E 8417	8429			418.3		
			F 8412	8429			418.8		
			G 8414	8429	Z 8370	8382	418.6		
							418.5	418.3	4
Weighted Mean,							418.2°	418.3°	
Antimony Point. 629.2°									
24	-0.1	-1	A 5509	5508	Y 5550	5546	629.2°	629.4°	2
25	-0.5	-5	A 5496	5508	Y 5529	5545	629.0	629.9	2
33	-0.1	-1	A 5513	5508	Y 5553	5544	629.2	629.3	2
34	-0.5	-5	A 5505	5508	Y 5537	5543	629.1	629.9	2
52	-0.5	-5	A 5505	5508			629.6		
			D 5490	5492	Z 5463	5460	629.2		
							629.4	629.1	2
74	-0.2	-2	A 5514	5504			628.2		
			E 5533	5530			628.8		
			F 5526	5530			629.5		
			G 5527	5530	Z 5461	5461	629.4		
							629.0	629.1	4
87	-0.3	-3	F 5517	5530			628.9		
			E 5517	5530			628.9		
			A 5481	5504			629.9		
			G 5513	5530	Z 5437	5461	629.3		
							629.2	629.9	4
Weighted Mean,							629.1°	629.5°	
Silver Point. 960.0°									
6	+0.8	+9	W9070	9057	X 9100	9071	959.4°	958.0°	1
26	-0.3	-3	A 9087	9083	Y 9159	9141	959.9	958.6	2
27	-0.8	-9	A 9066	9083	Y 9119	9141	959.9	960.4	2
35	-0.7	-8	A 9079	9082	Y 9142	9141	959.7	959.4	1
36	-0.1	-1	A 9097	9082	Y 9163	9141	959.4	958.7	1
41	-0.3	-3	A 9083	9081	Y 9156	9141	959.6	958.5	2
42	-0.8	-9	A 9076	9081	Y 9131	9141	959.3	959.7	2
63	-0.6	-7	A 9079	9084			960.7		
			D 9048	9058	Z 9010	9019	961.2		
							960.9	961.1	2

TABLE VIII—(Continued)

Exp. No.	Integrated correction to outside elements  Degr's M.V.		Standard Elements				Temperature		Weight
			Outside Corrected	Fixed Pt.	Inside Uncor- rected	Fixed Pt.	By Outside Element	By Inside Element	
Silver Point—(Cont.)									
68	-0.7	-8	A 9080	9085			960.3°		
			D 9051	9058	Z 9013	9019	960.4		
							960.4	960.3°	2
76	-0.2	-2	A 9088	9082			959.2		
			E 9112	9113			959.7		
			F 9097	9113			961.2		
			G 9106	9111	Z 9002	9018	960.2		
							960.1	961.2	4
81	+0.3	+3	F 9132	9113			959.5		
			E 9131	9113			959.6		
			A 9083	9082			961.1		
			G 9125	9111	Z 9015	9018	960.0		
							960.0	961.5	4
88	+0.3	+3	F 9143	9113			959.0		
			E 9139	9113			959.4		
			A 9093	9082			960.7		
			G 9135	9112	Z 9026	9018	959.6		
							959.7	960.1	4
Weighted Mean,							959.9°	960.2°	
Gold Point. 1062.4°									
64	-0.3	-3	A 10262	10265			1062.4°		
			D 10226	10233	Z 10178	10193	1062.8		
							1062.6	1063.4°	2
69	-0.4	-4	A 10253	10266			1061.4		
			D 10217	10234	Z 10169	10193	1061.7		
							1061.6	1062.3	2
77	-0.3	-8	A 10255	10263			1061.2		
			E 10282	10295			1061.6		
			F 10263	10296			1063.4		
			G 10276	10294	Z 10161	10193	1062.1		
							1062.1	1063.3	4
82	+0.4	+4	F 10303	10296			1061.9		
			E 10304	10295			1061.8		
			A 10256	10263			1063.1		
			G 10296	10294	Z 10181	10193	1062.4		
							1062.3	1063.6	4
Weighted Mean,							1062.2°	1063.2°	
Copper Point. 1082.6° (Lower Pressure. $p_0=217-221\text{mm}$ )									
2	+1.2	+14	W10457	10478	X 10491	----	1081.7	----	1
9	+1.0	+12	W10495	10478	X 10555	----	1082.2	----	1
11	+1.2	+14	W10487	10478	X 10512	----	1083.1	----	1
18	+0.7	+8	A 10510	10502	Y 10612	10573	1082.2	----	2
19	-0.4	-5	A 10501	10502	Y 10584	10573	1082.0	1081.0	3

TABLE VIII—(Continued)

Exp. No.	Integrated correction to outside elements		Standard Elements				Temperature		Weight		
			Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	By Outside Element	By Inside Element			
Degr's M. V.											
Copper Point (Lower Pressure)—Cont.											
20	-0.8	- 9	A 10488	10502	Y 10555	10573	1082.1°	1082.5°	3		
28	-0.3	- 4	A 10512	10501	Y 10593	10573	1082.1	1081.4	3		
29	-0.9	-10	A 10494	10501	Y 10556	10573	1082.2	1083.0	3		
37	-0.6	- 7	A 10504	10501	Y 10576	10573	1082.0	1082.0	2		
38	-0.3	- 4	A 10509	10500	Y 10585	10573	1082.2	1081.9	2		
39	+0.7	+ 8	A 10517	10500	Y 10617	---	1082.3	---	2		
43	-0.3	- 4	A 10512	10500	Y 10595	10573	1082.2	1081.3	3		
44	-0.9	-10	A 10501	10499	Y 10568	10573	1082.0	1082.6	3		
45	+0.6	+ 7	A 10515	10499	Y 10617	----	1082.3	----	2		
89	+0.5	+ 6	F 10546	10534			1081.8				
			E 10544	10534			1081.9				
			A 10496	10503			1083.4				
			G 10538	10533			Z 10429			10432	1082.4
											1082.4
126*	+0.4	+ 5	E 10631	10534			1082.2				
			F 10627	10534			1082.6				
			G 10621	10533			1083.0				
			H 10623	10535			C 10567			10470	1083.0
											1082.7
Weighted Mean							1082.2°	1082.2°			
Copper Point—Cont. (Higher Pressure. $p_0=346-347^{\text{mm}}$ )											
60	-0.7	- 8	A 10500	10502			1083.4°				
			D 10465	10470			Z 10422			10432	1083.6
65	-0.8	- 9					1083.5	1084.1°	1		
							1083.0				
							1083.4				
70	-0.3	- 4					1083.2	1083.9	2		
							1082.4				
							1082.6				
78	-0.1	- 1					1082.5	1081.8	2		
							1081.4				
							1081.8				
83	+0.1	+ 1					1083.4				
							1082.3				
							1082.2			1083.7	4
							1082.1				
E 10535	10534	1082.1									
A 10488	10503	1083.5									
			G 10527	10533	Z 10403	10432	1082.7				
							1082.6			1084.6	4

\* Made with outside-wound furnace. See page 106.

TABLE VIII—(Continued)

Exp. No.	Integrated correction to outside elements		Standard Elements				Temperature		Weight
	Deg's	M.V.	Outside Corrected	Fixed Pt.	Inside Uncor- rected	Fixed Pt.	By Outside Element	By Inside Element	
Copper Point—Cont. (Higher Pressure)									
84	+0.7	+ 8	F 10544 E 10542 A 10493 G 10533	10534 10534 10503 10533	Z 10426	10432	1082.0° 1082.3 1083.8 1083.0 1082.8	1083.5 1083.7° 1082.9°	4
Weighted Mean, Mean of 2 pressures,							1082.5°		
Diopside Point. 1391.2°									
96	0.0	0	E 14227 F 14222 G 14245 H 14251	14228 14229 14229 14231	Z 14121	14108	1392.1° 1392.5 1390.7 1390.4 1391.4	1390.5°	1
97	+1.0	+13	E 14260 F 14254 G 14267 H 14295	14228 14229 14229 14231	Z 14156	14103	1392.4 1393.0 1390.4 1389.9 1391.4	1390.5	1
99	-0.1	- 1	E 14213 F 14195 G 14215 H 14212	14228 14229 14229 14231	Z 14099	14103	1394.5 1396.0 1394.4 1394.8 1394.9	1393.7	1
100	+0.7	+ 9	E 14251 F 14244 G 14268 H 14273	14228 14229 14229 14231	Z 14156	14103	1394.4 1395.0 1393.1 1392.9 1393.8	1391.8	1
103	-0.4	- 5	E 14211 F 14204 G 14217 H 14230	14228 14229 14229 14231	Z 14124	14103	1392.5 1393.1 1392.1 1391.2 1392.2	1389.4	3
104	+1.0	+13	E 14242 F 14212 G 14249 H 14262	14228 14229 14229 14231	Z 14155	14103	1392.5 1394.9 1392.0 1391.1 1392.6	1389.3	3

TABLE VIII—(Continued)

Exp. No.	Integrated correction to outside elements		Standard Elements				Temperature		Weight
			Outside Corrected	Fixed Pt.	Inside Uncor- rected	Fixed Pt.	By	By	
							Outside Element	Inside Element	
Dioptside Point—(Cont.)									
106	- 0.6	- 8	E 14228	14228	Z 14123	14103	1391.7°	1390.0°	2
			F 14225	14229			1392.0		
			G 14233	14229			1391.8		
			H 14243	14231			1390.7		
						1391.4			
107	+ 0.9	+ 12	E 14248	14228	Z 14152	14103	1391.9	1389.4	2
			F 14237	14229			1392.8		
			G 14245	14229			1392.2		
			H 14252	14231			1391.8		
						1392.2			
130	- 0.6	- 7	E 14243	14228	C 14146	14153	1390.2	1392.0	3
			F 14241	14230			1390.6		
			G 14249	14230			1389.9		
			H 14239	14228			1390.6		
						1390.3			
Weighted Mean,							1392.0°	1390.4°	
Nickel Point. 1452.3°									
109	+ 0.7	+ 8	E 15028	14977	Z 14903	14850	1451.2°	1451.1°	1
			H 15027	14980			1451.6		
							1451.4		
111	0	0	E 14980	14977	Z 14867	14850	1453.2	1452.1	2
			H 14978	14980			1453.7		
							1453.5		
112	+ 0.9	+ 11	E 14971	14977	Z 14872	14850	1453.8	1451.5	2
			F 14958	14978			1454.9		
			H 14991	14980			1452.4		
						1453.7			
123	- 0.6	- 7	E 14984	14977	A 14982	14945	1454.3	1451.8	2
			F 14989	14978			1453.9		
						1454.1			
124	+ 0.8	+ 10	E 14989	14977	A 14996	14945	1454.6	1451.5	1
			F 14994	14978			1454.3		
						1454.5			
133	- 0.3	- 4	E 14954	14977	C 14882	14898	1451.9	1451.3°	4
			F 14958	14976			1451.5		
			G 14955	14981			1452.2		
			H 14946	14977			1452.5		
						1452.0°			
Weighted Mean,							1453.0°	1451.6°	



TABLE VIII—(Continued)

Exp. No.	Integrated correction to outside elements		Standard Elements				Temperature		Weight
			Outside Corrected	Fixed Pt.	Inside Uncor- rected	Fixed Pt.	By Inside Element	By Outside Element	
	Degr's	M. V.							
Cobalt Point. 1489.8°									
115	+0.1	+ 1	E 15390 F 15375	15439 15435	A 15357	15409	1488.7° 1489.6 1489.1	1488.9°	3
116	+1.4	+17	E 15428 F 15434 G 15435	15489 15485 15441	A 15421	15409	1490.5 1489.7 1490.1 1490.1	1488.6	3
118	-0.5	- 6	E 15385 F 15383 G 15393	15439 15435 15441	A 15382	15409	1491.7 1491.6 1491.3 1491.5	1489.6	2
120	-0.4	- 5	E 15381 F 15371 G 15363	15439 15435 15441	A 15379	15409	1491.7 1492.1 1493.3 1492.7	1489.4	1
121	+0.7	+ 9	E 15406 F 15405 G 15398	15439 15435 15441	A 15412	15409	1492.0 1491.8 1492.8 1492.2 1490.6°	1489.1 1489.0°	1
Palladium Point. 1549.2°									
134	-0.7	- 9	E 16151 F 16161 G 16139 H 16147	16143 16138 16145 16145	C 16075	16058	1549.5° 1548.3 1550.6 1550.1 1549.6°	1548.8°	
Anorthite Point. 1549.5°									
134	-0.7	- 9	E 16151 F 16161 G 16139 H 16147	16148 16141 16148 16145	C 16075	16060	1549.9° 1548.6 1550.9 1550.0 1549.9°	1549.0°	
Interpolation Points.									
49	-0.1	- 1	A 2486 D 2482	2492 2486	Z 2462	2465	320.2° 320.0 320.1 320.0°	319.9°	
Mean for cadmium,									
51	0.0	0	A 4451 D 4439	4450 4442	Z 4413	4417	524.6 525.0 524.8 524.9°	525.1	
Mean for A = 4450,									

TABLE VIII—(Concluded)

Exp. No.	Integrated correction to outside elements		Standard Elements				Temperature		Weight
			Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	By Inside Element	By Outside Element	
Degr's M. V.									
Interpolation Points—(Cont.).									
62	0.0	0	A 7895	7900	Z 7829	7848	854.2°	855.5°	
			D 7869	7881			854.9		
							854.6		
67	-0.2	-2	A 7883	7900	Z 7820	7848	854.0	855.0	
			D 7859	7881			854.5		
							854.3		
							854.7°		
Mean for A = 7900,									
128	-0.2	-2	E 12004	12000	C 11914	11928	1206.3	1207.8	
			F 12001	12001			1206.7		
			G 12008	12001			1206.1		
			H 12000	12003			1206.9		
							1206.5		
132	+0.1	+1	E 11947	12000	C 11887	11928	1206.0	1205.0	
			F 11952	11097			1205.3		
			G 11950	12001			1205.8		
			H 11941	12003			1206.8		
							1206.0		
Mean for E = 12000,									
							1206.4°		
129	-0.6	-5	E 13107	13100	C 18007	13028	1297.4	1299.3	
			F 13102	13101			1297.9		
			G 13110	13101			1297.2		
			H 13101	13103			1298.1		
							1297.7		
Mean for E = 13100,									
							1298.5°		

(Continued from p. 140.)

If the investigator's responsibility could be made to end with the representation of his own observations, no serious difficulty would arise, but such a formula when published is placed in the hands of many who do not realize that no physical significance was attached to the formula by its author and that its extrapolation in either direction would be fraught with grave danger. A mere inspection of the equation is sufficient to show that the electromotive force does not become zero for zero temperature, thereby immediately proving that extrapolation downward does not correspond to the observed readings of the thermoelement. In the Reichsanstalt equation this constant term was in fact sufficiently large to lead to absurdities if the extrapolation was continued far below 300°.

Notwithstanding the warning contained in this situation, extrapolation upward of the thermoelectric curve has been

employed almost universally for the determination of temperatures above  $1100^{\circ}$ , not only for direct determinations of temperature with the thermoelement itself, but also for the calibration of optical pyrometric apparatus. The absence of absolute determinations in this region has left this practice in undisturbed security until recently, when some doubt has been thrown upon the validity of irresponsible upward extrapolation by various observations. (1) The increase in the accuracy now attainable with the optical pyrometer has given an independent thermal scale comparable with that of the thermoelement and overlapping the same region. The two curves have not been found to correspond. (2) Experimental determinations of the melting point of platinum by continuing observations of the thermoelement up to a point where a portion of its platinum wire melts, have been undertaken in the national laboratories of Germany, England and the United States, and have yielded a value measured upon the extrapolated thermoelectric curve of about  $1710^{\circ}$ . The agreement in the different determinations was good and the result found general acceptance for a time. More recently, Holborn and Valentiner have made successful measurements with the gas thermometer at the temperature of melting palladium, and although high accuracy was not attempted, it became clear that the palladium point obtained by extrapolating with the thermoelement was much too low and by inference the platinum point also, for the various optical methods give opportunity for a very good determination of the temperature difference between the melting points of the two metals. The most recent estimates of the platinum melting point obtained in this way place it between  $1750^{\circ}$  and  $1775^{\circ}$ , indicating that the upward extrapolation with the thermoelement has given rise to an error of about  $50^{\circ}$  at the platinum point.

The data obtained in the present investigation throw much light upon this situation. If we take the observations of our series over the range covered by the Reichsanstalt scale ( $300^{\circ}$  to  $1100^{\circ}$ ) and write an equation for these of the same type as that used at the Reichsanstalt, it will read,

$$E = -302 + 8.2356t + .0016393t^2$$

and this equation will reproduce the temperatures of the standard melting points which fall in this region with a maximum error of 3 microvolts, an accuracy far within the errors of observation. But if we extrapolate this curve in accordance with the general practice above described, and compare the resulting electromotive forces with our observations between  $1100^{\circ}$  and

1550°, a somewhat startling surprise awaits us. Although the curve below the copper point is a practically perfect reproduction of the observations, it diverges from the gas thermometer scale at the melting point of palladium by 245 microvolts, which represents a temperature error of nearly 20°. This comparison is made in the table below :

	Temperature	Observed Microvolts	Calculated Microvolts	Observed— Calculated Microvolts
Zinc .....	418.2°	3429	3429	0
Antimony ...	629.2	5530	5530	0
Silver .....	960.0	9113	9115	-2
Gold .....	1062.4	10295	10298	-3
Copper .....	1082.6	10534	10534	0

*Extrapolation.*

	1207.1	12000	12027	-27
	1298.8	13100	13161	-61
Diopside ....	1391.2	14228	14338	-110
Nickel .....	1452.3	14945	15112	-167
Cobalt .....	1489.8	15439	15608	-169
Palladium ...	1549.2	16143	16388	-245

If, on the other hand, we follow Day and Clement, and represent  $t$  as a function of  $E$ , using the same data as before, the equation will take the form

$$t = 47.2 + .11297E - 1.3946(10)^{-6}E^2$$

This curve passes through the fixed points below 1100° nearly as accurately as the previous one, and is also quite competent to interpolate temperatures throughout the range of the old standard scale. Extrapolating this in turn up to the palladium point and comparing it with our gas thermometer measurements in the higher region leads to temperatures about 40° too low.

	Observed	Calculated	Observed— Calculated
Zinc .....	418.2°	418.2°	0°
Antimony ...	629.2	629.3	-0.1
Silver .....	960.0	960.9	-0.9
Gold .....	1062.4	1062.4	0
Copper .....	1082.6	1082.5	+0.1

*Extrapolation*

	1207.1	1202.0	+5.1
	1298.8	1287.8	+11.0
Diopside ....	1391.2	1372.0	+19.2
Nickel .....	1452.3	1424.0	+28.3
Cobalt .....	1489.8	1459.0	+30.8
Palladium ...	1549.2	1507.0	+42.2

The untrustworthiness of the present practice of extending thermoelement values obtained below  $1100^{\circ}$  into the region above that temperature is therefore abundantly demonstrated.\*

We were unable to find a simple parabola with which to represent the whole series of observations between  $300^{\circ}$  and  $1550^{\circ}$  within the errors of observation. The simplest procedure is therefore to divide the long curve into two parts. This plan is carried out below in the form in which it will probably be found most useful. A parabola passing through zinc, antimony and copper reproduces the results over that temperature range within the errors of observation. A similar parabola through copper, diopside and palladium gives the upper temperatures as accurately as they were measured. These two equations offer a means of safe and convenient interpolation throughout the entire range of the gas thermometer measurements. In this series are included certain gas thermometer measurements given at the end of Table VIII which were made at temperatures between the fixed melting points, for the purpose of checking the interpolation formula, together with a single gas thermometer determination of the cadmium melting point. The temperature  $854.1$  appears here corrected by  $-0.6^{\circ}$ , since the series, of which this measurement formed a part, showed a systematic difference of about this amount from the final average of antimony and silver, which lie on either side of this point.

*Cadmium to Copper*

$$E = -302 + 8.2356t + .0016393t^2$$

	Temperature	Observed Microvolts	Calculated Microvolts	Observed— Calculated Microvolts
Cadmium .....	$320.0^{\circ}$	2504	2501	+3
Zinc .....	$418.2$	3429	3429	0
	$524.9$	4470	4472	-2
Antimony .....	$629.2$	5530	5530	0
	$854.1$	7927	7928	-1
Silver .....	$960.0$	9113	9115	-2
Gold .....	$1062.4$	10295	10298	-3
Copper .....	$1082.6$	10534	10534	0

*Copper to Palladium*

$$E = -1941 + 11.1746t + .00032161t^2$$

Copper .....	$1082.6$	10534	10534	0
	$1207.1$	12000	12010	-10
	$1298.8$	13100	13112	-12
Diopside .....	$1391.2$	14228	14228	0
Nickel .....	$1452.3$	14977	14967	+10
Cobalt .....	$1489.8$	15439	15421	+18
Palladium .....	$1549.2$	16143	16143	0

\* For an account of some of the dangers of careless interpolation, see Day and Clement, loc. cit., p. 453.

It is possible to write a cubic equation which will reproduce the entire series from zinc to palladium without error greater than the normal accuracy of the observations themselves. The equation offered makes no pretensions to a least square solution with balanced residuals, but is arranged so that the greatest uncertainties are found in that portion of the curve where the greatest experimental error lies. The coefficients were rounded off for convenience of computation.

*Cadmium to Palladium*

$$E = -169 + 7.57t + 0.002648t^2 - 0.0000004724t^3$$

	Temperature	Observed Microvolts	Calculated Microvolts	Observed— Calculated Microvolts
Cadmium .....	320.0°	2504	2509	—5
Zinc .....	418.2	3429	3425	+4
	524.9	4470	4466	+4
Antimony .....	629.2	5530	5525	+5
	854.1	7929	7934	—5
Silver .....	960.0	9113	9121	—8
Gold .....	1062.4	10295	10296	—1
Copper .....	1082.6	10534	10530	+4
	1206.4	12000	11988	+12
	1298.5	13100	13091	+9
Diopside .....	1391.2	14228	14215	+13
Nickel .....	1452.3	14977	14963	+14
Cobalt .....	1489.8	15439	15424	+15
Palladium .....	1549.2	16143	16157	—14

6. *Analysis of Metals.* (By E. T. Allen.)

The object of these analyses was primarily, of course, to decide whether the metals should be used or rejected for the temperature scale, and those selected were examined very carefully so that in the future, when more is known about the specific lowering which the various impurities produce on the melting point, corrections may be made if desirable.

The accuracy of the determinations is problematical. There is of course the possibility of increased solubility of difficultly soluble compounds in the comparatively concentrated solutions of the metals from which the impurities have to be precipitated, viz., 5 to 6 g. in 250<sup>cc</sup> volume. Also, when it is necessary to separate the bulk of the metal by precipitation from the impurities, as it sometimes is, one cannot be sure that the impurity sought is not occluded by the precipitates. In most cases, the latter source of error is probably the more serious. Only methods worked out synthetically with materials laboriously prepared could decide these questions. Large quantities of metal, 25 to 100 g., were generally taken for analysis, and

since the impurities were weighed to the tenth of a milligram, the results are generally stated to the ten-thousandth of a per cent. This does not mean that the results are considered accurate to this figure. The variation in successive determinations comes in the thousandths, so that the fourth decimal place may have about as much value as the second in an ordinary analysis. Great pains have been taken to purify precipitates, often by many precipitations, so that in all cases the figures given may be regarded as minima. In all cases, too, I have endeavored to avoid missing anything, by repeating every process, rejecting no precipitate or solution until it was decided that nothing more was to be gotten from it. In any reasonable case of suspicion, blank determinations were made with the reagents.\*

#### *Heraeus' Palladium.*

The palladium was naturally suspected to contain other metals of the platinum group. It is well known that the separation of these metals is a problem of unusual difficulty. The plan here was therefore to precipitate most of the palladium from solution as one of its characteristic compounds and, while the filtrate was reserved for impurities, to redissolve and again precipitate the metal as another characteristic compound. In this way it was hoped that those impurities which were retained by the first precipitate would not be occluded by the second. The sheet metal was first cut into shavings on a milling machine which was especially cleaned for the purpose. Then the shavings were boiled a short time with dilute hydrochloric acid to remove any iron from the surface, washed and dried. After an unsuccessful endeavor to dissolve the palladium in nitric acid (insoluble brown hydroxide (?) always formed), it was dissolved in aqua regia and rid of nitric acid by successive evaporations with excess of hydrochloric acid. It was then dissolved in dilute hydrochloric acid and diluted further to about 1 l. Ammonia was added in excess.† A precipitate came down and redissolved on warming—all but a little ferric hydroxide which was filtered off. The filtrate was then evaporated again to about 250°, diluted and precipitated with stirring, by dilute hydrochloric acid. The voluminous precipitate of  $\text{PdCl}_2 \cdot 2\text{NH}_3$  was now filtered and washed on a Büchner porcelain funnel, using suction. The filtrate we will call "solution A." The precipitate was then dried and

\* After considerable experience in the examination of these "pure" metals, the writer has reached the conclusion that a 10 g. portion, in the great majority of cases, will give as satisfactory results as a larger portion and with far less labor.

† E. F. Smith and H. F. Keller, Amer. Chem. Jour., xiv, 423, 1892.

ignited in a large porcelain crucible. The resulting metal was dissolved in aqua regia and freed of nitric acid. This solution was diluted and precipitated by potassium iodide, and the filtrate—"solution B"—removed as above.

From solutions A and B, separately, the platinum metals were first removed by long boiling with ammonium formate. The metal—1 to 2 g. in weight, mostly palladium—was filtered and the filtrate and washings were examined further for other heavy metals by the usual methods.

*Separation of the Palladium from the Platinum Metals.*—Considering now the ammonium formate precipitate, Erdmann and Makowka\* have obtained satisfactory separations of palladium from platinum and iridium by treating the solution of the mixed chlorides with acetylene. Palladium comes down as acetylide and the other metals are unprecipitated. I found also that *rhodium* solutions even on heating were not precipitated by acetylene. As for osmium, the ease with which it oxidizes and the high volatility of its oxide makes its elimination, in the process of preparing the palladium, fairly certain. Ruthenium, the rarest element among the platinum metals, need hardly be looked for; still it was sought for in the iridium found. The acetylene method was used, for lack of a safer one, though very tedious. In solutions at all concentrated, I find the palladium ceases to precipitate long before it is entirely removed from solution. Perhaps this is due to the accumulation of acid liberated in the process. At least, when the solution is separated from the acetylide, evaporated and diluted again, acetylene brings down another portion. After five or six operations, a residual solution was obtained on which acetylene had no further action. The acetylide was now carefully ignited with a little ammonium nitrate, the metal redissolved, and the whole process repeated. The residual solution was then added to the first and from it  $\text{NH}_4\text{Cl}$  brought down platinum. In the chlor-platinate no iridium was found. It was ignited and the metal was entirely soluble in a few drops of aqua regia. It was again precipitated with  $\text{NH}_4\text{Cl}$  and finally weighed as platinum— $\text{Pt} = 1.6 \text{ mg.} = 0.007 \text{ per cent.}$  No rhodium was found in the filtrate. In the attempt to dissolve in aqua regia the several portions of metal formed by igniting the acetylide, tiny insoluble residues accumulated. These were fused with  $\text{KHSO}_4$ , which, as is well known, dissolves palladium and rhodium but not iridium or platinum if the temperature is kept low. The soluble portion was dissolved in water and precipitated with ammonium formate. It turned out to be palladium, since it was precipitated by potassium iodide and no trace of rhodium was found.

\* *Zeitschr. anal. Chemie*, xlvi, 146, 147, 1907.



The portion insoluble in  $\text{KHSO}_4$  was freed from silica (which came from the dish) by  $\text{HCl} + \text{HF}$ , ignited, and weighed.  $\text{Ir} + [\text{Ru}] = 1.9 \text{ mg.} = 0.008 \text{ per cent.}$  When fused with  $\text{K}_2\text{CO}_3 + \text{KNO}_3$ , some blue insoluble  $\text{IrO}_3$  was formed, but the fusion showed no yellow color, and in view of the minute quantity of material, it was not thought worth while to search more carefully for ruthenium.

The final precipitate of palladium acetylide was changed to chloride, diluted, and saturated with  $\text{SO}_2$  for gold, but none appeared.

Nothing else was found in the metal except a trace of copper. The iron found earlier had to be reprecipitated several times from chloride solution by ammonia to get rid of palladium. The precipitate was finally transformed into sulphate and determined volumetrically.— $\text{Fe} = 2.6 \text{ mg.} = 0.10 \text{ per cent.}$

#### *Analysis of Palladium.*

Au.....	none
Ru.....	none
Rh.....	none
Pt.....	0.007%
Ir.....	0.008%
Cu.....	trace
Zn.....	doubtful trace
Fe.....	0.10%
	<hr/>
	0.025%

#### *Kahlbaum's Electrolytic Nickel.*

Two 50 gram portions were dissolved separately in measured quantities of nitric acid and then carried to white fumes with excess of sulphuric acid. Both portions were then dissolved in water and filtered. There was a small dark residue which was washed thoroughly and extracted with aqua regia, leaving a little silica from the dish. The yellow chloride obtained was freed from nitric acid, saturated with  $\text{SO}_2$ , and left to stand. *No gold.* Changed to chloride again and tested with caustic soda and  $\text{H}_2\text{O}_2$ . *Still no gold.* Acidified and reprecipitated with  $\text{NH}_4\text{Cl}$ , a characteristic yellow precipitate was obtained. Confirmed by dissolving the chlor-platinate in hot water and precipitating by hydrogen.  $\text{Pt} = 2.3 \text{ mg.} = 0.0023 \text{ per cent.}$  The main solution was then precipitated by  $\text{H}_2\text{S}$  ( $v = 2 \text{ l.}$ ). The small black precipitate obtained was worked over for gold and platinum with the above.

Other heavy metals were tested for in the ordinary way.  $0.2 \text{ mg. PbSO}_4 = \text{about } 0.1 \text{ mg. Pb.}$   $\text{Cu} = 52.3 \text{ mg.} = 0.0523 \text{ per cent.}$

*Ammonium Sulphide Group.*—The voluminous solution was now freed from hydrogen sulphide by evaporation, some

ammonium persulphate was added and a stream of air passed through the solution for some time. *No manganese.*  $\text{Fe}_2\text{O}_3 = 6.1 \text{ mg.}$ , after repeated precipitation.  $\text{Fe} = 4.2 \text{ mg.}$  Repeated efforts were made to separate zinc with  $\text{H}_2\text{S}$  on the principle of the lower solubility of  $\text{ZnS}$  in dilute acids, but without satisfaction. First I tried to precipitate a small fraction of the nickel, hoping to get all the zinc with it. The volume of the solution was about 5 l. But unless so much acid was added that strong doubts were entertained of recovering any zinc that might be present, the fraction of the nickel precipitate was far too great. Again, all the nickel was precipitated and the precipitate was digested with cold 10 per cent solution of hydrochloric acid. Here one had to fear either the failure to remove the zinc or the removal of too much nickel to handle without so many precipitations that a small quantity of zinc would probably be lost. It is doubtful whether we have any method which will give very small amounts of zinc in metallic nickel.

The whole solution was now tested for cobalt as follows: It was freed from  $\text{H}_2\text{S}$  by evaporation, acidulated with  $\text{HCl}$  and precipitated by  $\alpha$ -nitroso- $\beta$ -naphthol in 50 per cent acetic acid. This was added in several portions. After long standing the precipitate was collected and washed. The voluminous precipitate was very cautiously burned in a capacious porcelain crucible. Much tar was formed. The residual oxide was dissolved in nitric acid and the cobalt separated from nickel by  $\text{KNO}_3$  in the usual way. The potassium cobalto-nitrite was finally decomposed by sulphuric acid and precipitated electrolytically from ammoniacal solution.  $\text{Co} = 101.4 \text{ mg.} + 4.9 \text{ mg.}$  recovered from filtrate and weighed as sulphate. Total = 0.1063 per cent.  $\text{Fe}$  and  $\text{Co}$  were also determined in a separate 10 g. portion of metal.  $\text{Fe}_2\text{O}_3 = 0.7 \text{ mg.}$   $\text{Fe} = 0.49 \text{ mg.} = 0.0049 \text{ per cent.}$   $\text{Co} = 10.3 \text{ mg.} = 0.1030 \text{ per cent.}$  A separate 10 g. portion was taken for sulphur. It was dissolved in nitric and evaporated on the water bath. This solution was diluted and precipitated with a slight excess of sodium carbonate. The filtrate was just acidulated, evaporated, and treated with barium chloride. No precipitate.

#### Analysis of Nickel.

Au .....	none	Bi .....	none
Pt .....	0.0023%	Cd .....	"
As .....	none	Zn .....	none found
Sb .....	"	Co .....	0.1063%
Sn .....	"	Mn .....	none
Pb .....	0.0001%	Fe .....	0.0042%
Cu .....	0.0523%	S .....	none
			<hr/>
			0.165%

*Kahlbaum's Cobalt.*

Two 25 g. portions of the metal in the form of powder were dissolved in 150<sup>cc</sup> water + 35<sup>cc</sup> concentrated  $H_2SO_4$ . The analysis was quite similar to that of the nickel. In the  $H_2S$  group were found:  $Cu = 8.9 \text{ mg.} = 0.0178 \text{ per cent.}$   $PbSO_4 = 12.9 \text{ mg.}$   $Pb = 0.0176 \text{ per cent.}$  In the  $(NH_4)_2S$  group manganese was tested for as in the nickel. None was found.  $Fe_2O_3 = 0.9 \text{ mg.}$   $Fe = 0.0006 \text{ per cent.}$  As the tests for Ni and Zn were unsatisfactory, another portion of 25 g. was dissolved in dilute sulphuric acid and precipitated by  $H_2S$ . The filtrate from the sulphides was filtered and freed from excess of  $H_2S$  by evaporation. Then it was diluted to 1 liter and divided into two portions. Both were neutralized by sodium carbonate. In the one, manganese was sought for by ammonium persulphate. In the other nickel was looked for. A little ammonia was added and then an alcoholic solution of dimethylglyoxime. A precipitate containing much cobalt was obtained. This was worked over for nickel but none was found. For sulphur the method used in the analysis of nickel was followed.  $BaSO_4 = 14.4 \text{ mg.,}$  blank = 5.1 mg., difference = 9.3 mg.,  $S = 0.013 \text{ per cent.}$

*Analysis of Cobalt.*

Ag .....	none	Cu .....	0.0178%
Au .....	"	Bi .....	none
Pt .....	"	Cd .....	"
As .....	"	Zn .....	"
Sb .....	"	Ni .....	"
Sn .....	"	Fe .....	0.0006%
Pb .....	0.0176%	Mn .....	none
		S .....	0.013%
			<hr/>
			0.049%

*Aluminum.*

Owing to the difficulty of handling this metal, small portions (10 g.) only were taken for analysis. *Heavy metals*, except arsenic and antimony, were sought for in the hydrochloric acid solution by ordinary methods. Only a trace of copper was found.

*Phosphorus, Arsenic, and Sulphur.*—For these elements, a separate portion was dissolved in caustic alkali in a special apparatus entirely of glass. The vessel was first filled with purified hydrogen and then the alkali was introduced and the gases evolved were passed through silver nitrate solution. At the end, the gases remaining in the vessel were displaced by hydrogen. The precipitated silver was worked over for the different elements. *No As nor Sb.* A separate portion was used for sulphur.  $BaSO_4 = 1.4 \text{ mg.}$   $S = 0.002 \text{ per cent.}$

*Silicon.*—10 g. metal were dissolved in a mixture of nitric and sulphuric acids, using a platinum dish. With hydrochloric acid alone nearly all the silicon is lost as hydride. The brown amorphous residue was filtered, washed and fused with sodium carbonate. From the fusion silica was obtained in the usual way.  $\text{SiO}_2 = 41.4$  mg.  $\text{Si} = 0.194$  per cent. Repetitions gave 0.189 per cent and 0.190 per cent.

*Carbon.*—10 g. metal were dissolved in NaOH and filtered through glowd asbestos, washed first with water, then with dilute acid and finally with water and dried at  $105^\circ$ . The asbestos and residue were then transferred to a combustion tube and burned in air free from  $\text{CO}_2$ . The gases were passed through standard  $\text{Ba}(\text{OH})_2$ . A considerable precipitate was obtained, while a blank gave no trace. The excess of  $\text{Ba}(\text{OH})_2$  was the nitrated with standard acid using phenolphthalein as indicator. 5.05 mg.  $\text{CO}_2$  found.  $\text{C} = 0.014$  per cent. A duplicate in which the metal was dissolved in KOH gave 0.012 per cent.

*Iron.*—10 g. metal were dissolved in hydrochloric acid, and to the solution was added tartaric acid free from iron. From this solution the iron was precipitated by colorless ammonium sulphide. The precipitate was finally changed to sulphate and determined volumetrically.  $\text{Fe} = 4.6$  mg. Blank determination gave 0.3 mg.  $\text{Fe} = 0.043$  per cent.

*Calcium, Sodium, and Potassium* were sought for in the hydrochloric acid solution, by precipitating with ammonia, washing the large precipitate and testing the evaporated filtrate. *No Ca.* Some alkaline chloride was found, but a blank showed that it came from the ammonia, as there was only a difference of 1.6 mg. between the chloride of the blank and that in the determination. *No Na or K.*

#### Analysis of Aluminum.

As .....	none	C .....	0.013%
Sb .....	"	S .....	0.002%
P .....	"	Ca .....	none
Cu .....	0.003%	Na .....	"
Fe .....	0.043%	K .....	"
Si .....	0.190%		
			0.251%

#### Antimony.

25 g. metal were powdered in an agate mortar and treated with 35 per cent  $\text{HNO}_3$  on the steam bath. As soon as the reaction was practically complete, the antimonious acid was extracted

with hot dilute nitric acid, transferred to a filter and washed with water. The filtrate and washings were then evaporated to dryness with hydrochloric acid, while the antimonie acid was digested repeatedly with yellow sodium sulphide till the soluble portion was dissolved. The residue, after a little washing, was dissolved in nitric acid, evaporated to dryness, freed from nitric by hydrochloric acid, and the chlorides united with the first extract. The whole was precipitated by hydrogen sulphide. The washed sulphides were then extracted with colorless ammonium sulphide. From this solution the sulphides were thrown down by acid, filtered and washed. Then they were dissolved in hot dilute caustic potash. The solution was boiled with perhydrol for complete oxidation, and arsenic sought for by Fischer's method, viz., reducing by ferrous ammonium sulphate and distilling in a current of hydrochloric acid gas. *No As.*

A separate portion of 5 g. was taken for tin. McCay's method was tried.\*  $\text{SnO}_2 = 1.3 \text{ mg.}$   $\text{Sn} = 1.0 \text{ mg.} = .02 \text{ per cent.}$

A separate portion of 25 g. was used for sulphur. The metal was oxidized by nitric acid as before, and the soluble portion separated and evaporated. The residue was then heated with a small excess of sodium carbonate and filtered. The residue was also boiled out several times with sodium carbonate solution. The two solutions were then acidified with hydrochloric acid and treated with barium chloride. The portion soluble in nitric acid gave a slight precipitate, which was further purified, after the usual washing and drying, by fusion with sodium carbonate. The water extract containing the soluble sulphate was acidified and precipitated a second time.  $\text{BaSO}_4 = \text{trace.}$

#### *Analysis of Antimony.*

As.....	none	Cd .....	none
Sn.....	0.02 (?)	Ni .....	"
Ag.....	none	Co .....	"
Pb.....	trace (?)	Mn .....	"
Cu.....	0.004	Zn .....	"
Bi.....	none	Fe.....	0.007%
		S .....	trace (?)
			<hr/>
			.031%

In the following table, the results of these and previous† analyses of metals for the temperature scale are summarized :

\* Private communication.

† Day and Clement, loc. cit., p. 454.

Summarized Analyses of Metals.\*

Impurities stated in fractions of 1%	Metals							
	Palla- dium	Cobalt	Nickel	Copper	Silver	Alum- inum	Antimony	Zinc
Pt	0.007	none	0.0023	0.011†	0.001			
Ir	0.008							
Rh	none							
Ru	"							
Au	"	none	none	none	0.0005			
Se				"				
Te				"				
As		none	none	"	none	none	none	none
Sb		"	"	"	"	"		0.002
Sn		"	"	"	"		0.02 (?)	
Hg					"		none	
Ag		none	none	0.0006			"	none
Pb	none	0.0176	0.0001	none	0.0008			0.051
Bi	"	none	none	"	none		none	none
Cu	trace	0.0178	0.0523		trace	0.003	0.004	none
Cd	none	none	none	none	none		none	0.004
Ni	"	"		"	"	none	"	none
Co	"		0.1063	"	"	"	"	"
Fe	0.010	0.0006	0.0042	0.0038	0.0011	0.043	0.007	0.006
Zn	trace?	none?	none?	0.0007	none		none	
Mn		none	none				"	
Si				none		0.190		none
C					0.0003	0.013		
S		0.013	none	0.0020	0.0004	0.002		none
P						none		
Ca						"		
Na						"		
K						"		
Total	0.25	0.49	1.65	0.08	0.03	251	0.31	0.63

\* A blank opposite any impurity means that it was not looked for.

† Means platinum metals.

### 7. Conclusion.

It is now something over five years since the Geophysical Laboratory took up the task of redetermining the absolute temperature scale from 300° to 1100° with the nitrogen thermometer, and of extending it, if it should prove practicable to do so, to 1600° C., for it is in this upper region that most of the mineral relations which it is the chief purpose of the laboratory to study are found. Two preliminary publications have been made during the investigation. One, a brief summary of preliminary work up to 1100°, was given before the National Academy of Sciences and the American Physical Society in April, 1907,\* the second covered the same ground at con-

\* Abstract, Phys. Rev. xxiv, 531, 1907.

siderable length in 1908.\* The present paper extends the observations to  $1550^{\circ}$ , and completes the work contemplated under the original plan.

No attempt will be made to offer an inclusive summary of the whole investigation. It is a record of experimental measurements covering an unusually wide range of details which do not admit of brief classification. The errors which have heretofore been present in measurements with the nitrogen thermometer have been reduced by the present investigation to about one-fourth their former magnitude and the certainty of their evaluation is at least proportionately increased.

The chief source of present uncertainty is the temperature distribution over the surface of the bulb in an air bath. No indication of a limit to the temperature attainable with the nitrogen thermometer or to its ultimate accuracy was discovered during the present investigation.

The magnitudes of the errors, and their effects on the temperature, are summarized in Table IV, page 129. The determinations of the expansion coefficient of the bulb material (80 Pt: 20 Rh) are summarized on pp. 131–132.

The melting temperatures of the metals and salts which have been used as fixed points to establish the new scale are brought together in the table below, together with the conditions under which the determinations were made. The generally accepted Reichsanstalt scale is printed beside it for convenient comparison. The analyses of the metals are summarized on p. 159.

To this table has been added a new estimate of the melting temperature of platinum, of which we could make no direct determination. Its general acceptance and availability as a fixed point of reference, and the wide disagreement between the direct determinations heretofore made of it, form a sufficient reason for its inclusion. The estimate is arrived at in this way: There is a remarkably close agreement between independent determinations of the *temperature interval* between the melting points of palladium and platinum:

Nernst and von Wartenberg†	$204^{\circ}$
Holborn and Valentiner (at the Reichsanstalt)‡	$207^{\circ}$
Waidner and Burgess (at the Bureau of Standards)§	$207^{\circ}$

If we therefore simply add  $206^{\circ}$  to our determination of the palladium point, we obtain  $1755^{\circ}$  as the melting point of pure platinum, with an absolute error of perhaps no more than  $\pm 5^{\circ}$ . The table follows:

\* This Journal (4), xxvi, 405, 1908.

† W. Nernst and H. von Wartenberg, Ber. d. Deutsch. phys. Ges., iv, pp. 48, 146, 1906.

‡ L. Holborn and S. Valentiner, Ann. d. Phys. (4), xxii, 1, 1907.

§ C. W. Waidner and G. K. Burgess, Bull. Bur. Standards, iii, p. 163, 1907.

Substance	Point	Atmosphere	Crucible	Temperature	The Reich- sanstalt Scale
Zinc	Melting and freezing	Air	Graphite	$418.2^{\circ} \pm 0.3$	419.0*
Antimony	Do.	Carbon monoxide	Do.	$629.2 \pm 0.5$	630.6
Silver	Do.	Do.	Do.	$960.0 \pm 0.7$	961.5
Gold	Do.	Do.	Do.	$1062.4 \pm 0.8$	1064.0
Copper	Do.	Do.	Do.	$1082.6 \pm 0.8$	1084.1
Diopside (pure)	Melting	Air	Platinum	$1391.2 \pm 1.5$	
Nickel	Melting and freezing	Hydrogen and Nitro- gen	Magnesia and Magne- sium Alum- inate	$1452.3 \pm 2.0$	
Cobalt	Do.	Do.	Magnesia	$1489.8 \pm 2.0$	
Palladium	Do.	Air	Pure Mag- nesia	$1549.2 \pm 2.0$	1575.*
Anorthite (pure)	Melting	Do.	Platinum	$1549.5 \pm 2.0$	

In addition, the following temperatures were incidentally obtained :

Cadmium	Melting and freezing	Air	Graphite	$320.0 \pm 0.3$	321.7
Aluminum	Freezing	Carbon monoxide	Do.	$658.0 \pm 0.6$	657.
Platinum	Melting	Air		1755.	

Geophysical Laboratory,  
Carnegie Institution of Washington,  
Washington, D. C., December 24, 1909.

\* Holborn and Valentiner, loc. cit.



ART. IX.—*A New Sclerometer*; by A. L. PARSONS (University of Toronto).

THE physical properties of minerals and metals have for a long time been a subject for investigation, and among the first of these properties to be studied were hardness and tenacity, but although the tensile strength and crushing point of the various substances are easily measured, the determination of hardness or resistance which a substance offers to abrasion is not so well understood. The sclerometer which was devised by Seebeck and later improved by Grailich and Peckarek is the one which is best known, but it is little used because the length of time which is required for a single measurement prevents the common use of an instrument which should be of valuable assistance to the mineralogist and metallurgist.

A bibliography of works on sclerometry is given by Jaggard\* which includes the most important papers and outlines the principles employed by various investigators in using their own instruments or those devised by others.

The new instrument differs from those of Seebeck, Grailich and Pekarek and others in that the force that is necessary to make a scratch is measured by means of a spring and not by weights.

*Description of the Instrument.*†

The instrument consists of four working parts on a base, as follows (see fig. 1):—

1. *Steel spring* (F) with test-point holder (H) fastened to the column (S).

2. *Object holder* (O) with divided horizontal circle (C), horizontal screw (1) for moving the object to be tested from side to side, and two vertical screws (2 and 3) to give the object the desired inclination.

3. Carriage (7) with transport screw (4) and spring (5) to move the test object, while making the scratch, and a slide (6).

4. Micrometer screw (E) and scale (8) to measure the elevation, which is proportionate to the force necessary to make a scratch.

5. Base (G) to hold the working parts together.

1. The spring (F) consists of a strip of steel 120<sup>mm</sup> long, from the column (S) to the test point, 4–8<sup>mm</sup> wide and 0.75<sup>mm</sup> thick. It is firmly fastened by a screw to the top of the

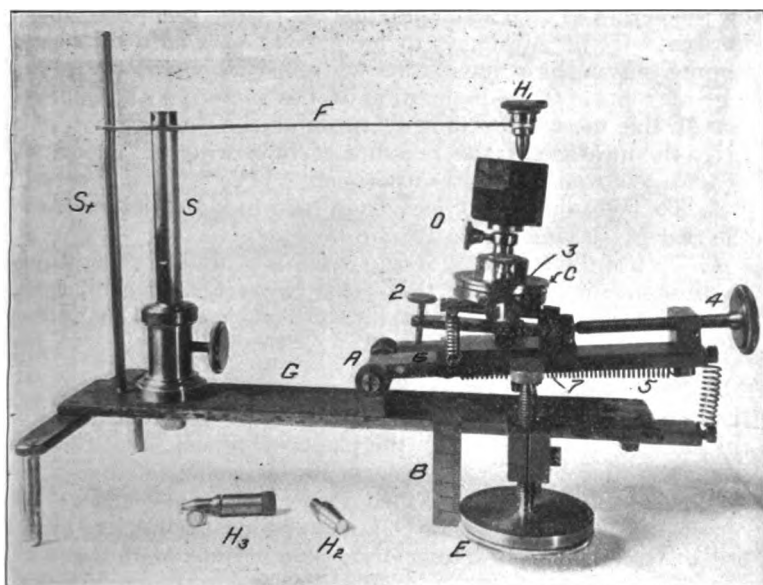
\* This Journal (4), iv, p. 399, 1897.

† Price of instrument, 80 marks from the mechanic, P. Stoe, Heidelberg, Germany, Jubilaeums Platz, 70.

column (S) and with this can be raised or lowered in the socket (B). The rod (St) behind the column prevents lateral movement of the spring in raising or lowering the same. On the free end of the spring is screwed the test point holder ( $H_1$ ,  $H_2$ , or  $H_3$ ) which carries the crystal point or metal point with which the test object is to be scratched.

The following three point-holders seem desirable and are provided with the instrument:  $H_1$  with diamond point. This is preferably a tetrahedral cleavage fragment, as this form gives

FIG. 1.



the sharpest cutting edge and is least liable to variations in hardness.  $H_2$ , a holder in which a needle of steel or other metal can be fastened. Generally a sewing needle is used, as there is little variation in hardness in needles from the same packet. For very soft substances a brass pin or a copper point may be employed.  $H_3$ , a holder with a cup-like depression in which a crystal or other substance may be fastened by means of wax "kit."\* This may be either a substance of *known* hardness with which another is to be compared or one of *unknown* hardness which is to be tested by scratching the surface of a substance whose hardness is known.

\* A piece of "kit" is provided with each instrument.

2. The object carrier (O) holds the crystal or other test object firmly in the position desired for making the tests. The crystal is fastened by wax "kit" to a small plate which is set in a socket at the top of the carrier.

The adjustment of the test object is as follows:

1. To bring the surface under the test point the transport screw (4) and the screw (1) are used. The screw (1) has also the purpose of moving the test object from side to side so that duplicate measurements may be made in parallel positions.

2. To give the face of the test object the desired inclination so that it forms with the slide (6) a wedge, it is tilted by means of the screw (2). The inclination will vary according to the hardness of the substance to be tested; very soft substances require only a slight inclination while harder materials require a greater one. This inclination of the surface to be tested is one of the most important features of the instrument, as it gives the measure of the pressure of the spring (F) when the crystal is moved by the transport screw (4).

3. To level the test object from side to side a screw (3) on the rear of the instrument is employed.

4. To test the hardness of the substance under investigation in different directions the graduated circle (C) is turned about its axis. This circle is divided into 36 parts so that each division gives  $10^{\circ}$ .

3. The transport screw (4) and accompanying spring (5) move the test object under the test point. The inclination of the surface to be tested to the plane of the slide (6) forms a wedge which by the movement of the screw (4) raises the spring (F) until a scratch is made.

4. The micrometer screw (E) raises or lowers the test object until it just touches the test point. Each division on the screw head measures an elevation of  $0.01^{\text{mm}}$ .

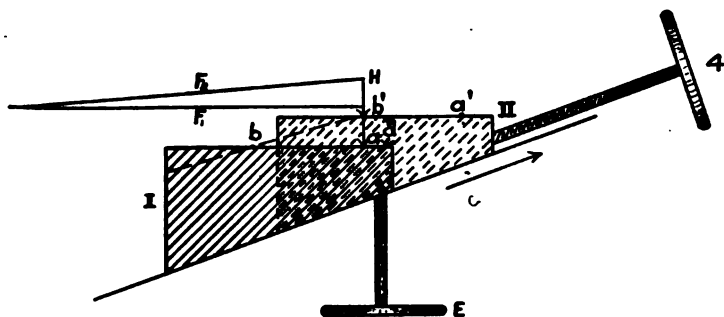
5. The base (G) carries the different parts and needs no particular description.

#### *Measurement.*

The crystal or other test object is fastened to the top of the object holder (O) and inclined by means of the screw (2) so that the face to be investigated forms a wedge with the track (6). By the screw (3) it is made horizontal from side to side. By raising or lowering the column (S) the test point is brought to a position where it nearly touches the surface to be tested. By means of the micrometer screw the crystal is then raised until the test point just comes in contact with the face to be tested at the point *a*, fig 2.

Now by means of the transport screw (4) and the accompanying spring (5) the crystal is moved in the direction indicated by the arrow points so that as the surface acts as a wedge the test point (H) is raised and the spring (F) is bent from position  $F_1$  to position  $F_2$ . By this movement a position is reached where the test point makes a scratch on the surface to be tested which is indicated in the figure as  $b$ . By the movement of the test object from position I to position II this point  $b$  has been brought to the position  $b'$  and the point  $b$  has also been raised the distance  $ab' = d$ . After the scratch has been made a reading is made on the micrometer screw E. The crystal is then lowered by means of the micrometer screw

FIG. 2.



until the test point just touches the crystal or other substance at the point  $b'$ , in other words at the beginning of the scratch, and a second reading is made on the micrometer screw which gives the distance  $ab'$  in divisions on the micrometer screw. This distance gives a measure of the bending of the spring or of the pressure necessary to make a scratch on the crystal, that is, it is a measure of the hardness.

In practice the lowering of the crystal by means of the micrometer screw gives a forward motion of the crystal in the direction of the arrow points in the figure and the beginning of the scratch must be brought under the test point by the transport screw (4). It is also found better in practice to lower the crystal or other test object so that the test point does not touch the surface, and then raise the test object again until the point just touches.

#### Calibration.

In this instrument the force that is necessary to make a scratch is measured by the strain on the spring (F) and the

reading is made in divisions on the micrometer screw (E). In the instruments of Seebeck and others this same force is measured by the weights with which the test point is loaded. This measurement by weights has the advantage that the weights are constant, while the bending of the spring (F) is dependent upon the material and dimensions of the same, and with each instrument we get a different factor. In order to reach comparable results it is necessary to reduce the divisions on the micrometer screw to measures of weight. This reduction of elevation to weight is called the *calibration of the instrument*.\*

The calibration of the instrument is made in this way. A glass plate is fastened to the object carrier and a scratch is made with the diamond point. The glass is now brought to the position where the test point just touches the beginning of the scratch. This point is determined when the test point just meets its reflection in the glass. The reading on the micrometer screw (E) is taken, the plate lowered by means of the micrometer screw and a weight placed on the test point holder (H) by which the spring is bent. The plate of glass is now raised until the test point just touches the beginning of the scratch and a second reading is made on the micrometer screw (E). Subtracting the second reading from the first gives the number of divisions on the micrometer screw that corresponds to a given weight.

By lowering the glass plate by means of the micrometer screws not only the plate but the track (6) and the object carrier (O) describe a small arc of a circle about A so that the beginning of the scratch must be brought under the point by means of the transport screw (4).†

The deflection of the spring for various weights is measured and a table can be made for all.

The results of the calibration are as follows:

	Weight	Reading	Deflection of needle in divisions of graduated circle	No. of divisions equivalent to 1 grm.	Mean No. of divisions equivalent to 1 grm.
	grm.				
First trial..	0	183.0	0		
	5	170.0	13	2.6	
	10	159.0	24	2.4	
	20	134.5	48.5	2.425	
	50	60.5	122.5	2.45	2.469

\* Every instrument is furnished with a calibration table so as to give the weight that corresponds to one division on the micrometer screw.

† A very slight error is thus introduced but in practice this can be neglected, as the determinations of hardness are made in the same way and the errors are comparable.

	Weight gram.	Reading	Deflection of needle in divisions of graduated circle	No. of divisions equivalent to 1 gram.	Mean No. of divisions equivalent to 1 gram.
Second trial.	0	211.5	0		
	5	199.0	12.5	2.5	
	10	186.5	25.0	2.5	
	20	162.5	49.0	2.48	
	50	86.0	125.5	2.51	2.4975
Third trial..	0	135.0	0		
	5	123.0	12.0	2.4	
	10	110.0	25.0	2.5	
	20	85.0	50.0	2.5	
	50	7.0	128.0	2.56	2.49
Fourth trial.	0	193.5	0		
	5	180.5	13.0	2.6	
	10	168.5	25.0	2.5	
	20	143.5	50.0	2.5	
	50	67.0	126.5	2.53	2.5325
Mean of all .....					2.4975

The results agree closely so that the elevation may be considered proportional to the weight and in this instrument a load of 10 grams is equivalent to 25 divisions on the micrometer screw.

#### *Results of Measurements.*

Plane and polished surfaces of glass, iron, copper, and brass were taken as test objects. A few trials were made with crystal faces, but further study is necessary before it can be stated that the instrument is suitable for determining the hardness of unpolished surfaces.

*Measurements with the diamond point* (a tetrahedral cleavage fragment):

A. *Copper*. 10 measurements: Pressure = 1.2, 1.2, 1.8, 1.6, 1.6, 1.4, 1.6, 1.8, 2.0, 1.4 gram. Mean of first five measurements = 1.48 gram.; mean of second five measurements = 1.44 gram.; mean of all 1.46 gram.

B. *Brass*. 10 measurements: Pressure = 1.6, 2.0, 2.2, 2.2, 2.0, 2.2, 2.2, 2.2, 1.6, 1.7 gram. Mean of first five measurements = 2.00 gram.; mean of second five measurements = 1.98 gram.; mean of all 1.99 gram.

C. *Iron* (rolled). 10 measurements: Pressure = 2.2, 1.8, 2.0, 1.6, 2.2, 2.0, 2.2, 1.8, 2.0, 1.8 gram. Mean of first five measurements = 1.96 gram.; mean of second five measurements = 1.96 gram.; mean of all 1.96 gram.

D. *Glass* (object glass for microscope). 10 measurements: Pressure = 3.8, 4.0, 4.2, 4.0, 4.0, 3.8, 4.2, 4.2, 4.2, 4.4 gram.

Mean of first five measurements = 4.0 grm.; mean of second five measurements = 4.16 grm.; mean of all 4.08 grm.

*Measurements with steel point* (sewing needle, number 5 sharp):

E. *Copper.* 10 measurements: Pressure = 5.0, 4.8, 4.0, 4.8, 4.0, 4.2, 3.8, 4.2, 4.2, 4.0 grm. Mean of first five measurements = 4.52 grm.; mean of second five measurements = 4.08 grm.; mean of all 4.3 grm.

F. *Brass.* 10 measurements: Pressure = 16.4, 12.0, 10.4, 10.4, 9.8, 14.0, 13.0, 10.8, 10.8, 10.4 grm. Mean of first five measurements = 11.8 grm.; mean of second five measurements = 11.8 grm.; mean of all 11.8 grm.

The ten measurements were made each time on the same piece of copper, brass, etc. with the same inclination of the surface and the same direction for the scratch. After each scratch the plate was moved a little to one side by means of the screw (1) so that the ten scratches were parallel and near each other.

The beginning of the scratch with the diamond point was always sharp and easily seen and is a very distinct point. With the steel needle, however, the beginning of the scratch on steel was somewhat uncertain. The scratch did not have a sharp beginning but was microscopic and gradually increased in depth with the increase of pressure.

In general a diamond point will probably give the best results for all substances except possibly for those which are extremely soft. Special study is being made to determine this point.

The nearly equal results obtained by scratching iron and brass with diamond were surprising and the two were tested against each other. The iron made a scratch on the brass very easily and the brass made a scratch on the iron but apparently with greater difficulty, but the point on the iron was, however, sharper than the point on the brass. It would appear that in the determination of hardness other properties such as tenacity, elasticity, flexibility, etc. must be taken into consideration, and it is hoped that this instrument may be of assistance in the study of the relations between these properties.

The results show a good determination when the mean of five measurements is taken.

The measurement is rapid and requires less than three minutes for a measurement when the test object is in position or for ten consecutive measurements less than a half hour.

*The advantages* of the instrument above mentioned are rapidity of observations, compactness, and cheapness. So far as observations have been made up to the present time, the instrument gives good results for polished faces of glass and metal, but further study is necessary to show its availability for minerals.

Heidelberg, Aug. 14, 1909.

ART. X.—*Dodecahedral Jointing due to Strain of Cooling*; by FRED. H. LAHEE.

IN the woods just south of Beacon St., and about a quarter of a mile west of Hammond St., Chestnut Hill, Mass., the Roxbury conglomerate is cut by a fine-grained, basaltic dike\* which, in some parts, disintegrates into small (average diameter,  $\frac{1}{8}$  in.), polyhedral, often roughly dodecahedral, fragments. The dike has approximately plane-parallel sides, is four feet thick, strikes N. 20° E., and dips 78° E., its attitude being parallel to a prominent joint set of the country rock. That it entered a relatively cool rock is indicated by the fact that its texture, moderately fine in the middle, becomes very fine at the contact. It contains occasional large phenocrysts (xenocrysts) of apatite and biotite, both of which are well shaped, and of pink acid feldspar, which has outlines made irregular by the invasion of short tongues of the groundmass.

Near the country rock, on each side, in a zone from four to ten inches wide, hexagonal columnar jointing is poorly developed perpendicular to the contact surface. Inwards, the columns give place to the polyhedral blocks already mentioned as conspicuous in the disintegration of the rock.

Obviously the joints† which give rise to such many-sided fragments are of small extent. Furthermore, they (the joints) often vary in direction, or may die out entirely; but in spite of this irregularity, it is not difficult to find blocks bounded by twelve rhombohedral faces that intersect one another at angles nearly equal to the similar angles of a perfect dodecahedron. The surfaces of the blocks are relatively coarsely granular, without a well-developed feather fracture, a feature not uncommon on the more finely textured hexagonal columns. Where the phenocrysts are in the path of fracture, the break either passes round the obstacle, or takes advantage of the mineral cleavage. These statements clearly point to the inference that the dodecahedral jointing, like the hexagonal, is an effect of tension due to cooling.

Hexagonal columnar jointing has long been so interpreted. In the ideal case, according to the principles of least action, the columns begin their development as a series of three-way fractures (each fissure at an angle of 120° to the other two) radiating from equally spaced points in a surface which is perpendicular to their (the columns') direction of growth. This type of fracture is therefore a two-dimensional, or surface, phenomenon, and the extension of the columns may be regarded

\*The writer wishes to thank Mr. R. W. Sayles for bringing this dike to his notice, and Professor Chas. Palache and Professor J. B. Woodworth, who discovered the dodecahedral jointing, for valuable suggestions.

†Similar jointing has recently been seen by the writer in trap dikes on Ragged Island, Casco Bay, Maine.



as the result of the regular inward advance of successively cooler planes, for each of which the temperature is uniform throughout.

If, on the other hand, we conceive of a *solid* which is losing heat equally in all directions and in such a way as to be subjected to a homogeneous strain, *six-way* fracture will develop instead of the *three-way* fracture of the cooling surface, and the resulting geometrical form will be a *dodecahedron* instead of a *hexagon*.

As hexagonal fracture may be illustrated by considering a series of equal tangent circles compressed uniformly from all directions in the same plane, so dodecahedral jointing may be experimentally demonstrated by subjecting a group of equal tangent balls, arranged in superposed horizontal layers, to equal pressure from every direction. Those spheres which were originally in contact with twelve others will, it is true, be dodecahedral; but whether they become regular rhombic dodecahedra or forms which, to borrow from crystallography, resemble a regular rhombic dodecahedron twinned parallel to an octahedral face, will depend on whether the centers of the balls of a given horizontal layer were above the centers of the spaces, or of the spheres, of the second layer below. In either case, prior to the compression, the conditions of unoccupied space and of equal distance between the centers of spheres will be fulfilled.

The literature appears to be lacking in references to the particular kind of jointing described. Much of the work on this subject was done several decades ago. At that time hexagonal jointing received considerable attention and was correctly explained as the result of uniform strain in a surface. Spheroidal structure, which was shown by Bonney to be often unrelated to fracture systems, was, however, held to be the analogous phenomenon in a solid, and perlitic structure was consigned to the same category. Bonney thus states his views:\* "A hexagon is the figure which will result from uniform contraction in two dimensions, a sphere from contraction in three dimensions." The case in point, however, leads to the conclusions: (1) that hexagonal columnar jointing is caused by equal tension in all directions in a surface at right angles to which the strain is differential; and (2) that uniform contraction in a solid must, under corresponding conditions of homogeneity, give rise to dodecahedral jointing. The sphere cannot be the exact analogue of the hexagon.

Cambridge, Mass.

\* Bonney, T. G., On Columnar, Fissile, and Spheroidal Structure. *Quart. Jour. Geol. Soc., Lond.*, xxxii, p. 152, 1876. On this subject see also Jukes, J. B., and Geikie, A., *Student's Manual of Geology*, 3d ed., 1872, pp. 182, 183, 311; Mallet, R., *Phil. Mag.*, Ser. 4, vol. i, pp. 122, 201; Scrope's *Volcanoes of Central France*, p. 92; Iddings, J. P., *The Columnar Structure in the Igneous Rock on Orange Mountain, New Jersey*, this *Journal*, (3), xxxi, p. 321, 1886, and Iddings, J. P., *Igneous Rocks*, N. Y., 320, 1909.

ART. XI.—*Restoration of Paleolithic Man*; by RICHARD SWANN LULL. (With Plate I.)

[Contribution from the Paleontological Laboratory, Peabody Museum, Yale University.]

AN attempt has recently been made by the writer to restore in plastic form the type of mankind dwelling in Europe during a portion of the Paleolithic period and variously known to science under the names of *Homo primigenius*, *neanderthalensis* or *mousteriensis*. The restoration, which is life size, is a tentative one and will be kept in the clay for a time in order that authoritative criticism may be met before it is cast in plaster (cf. Plate I).

The model is based mainly upon what is known as the "Man of Spy No. 1"; one of the two specimens found at Spy in Belgium, of which the museum contains excellent plaster casts. The illustrations of the remains of man found at Krapina in Croatia and described by Professor Gorjanovic-Kramberger in his "Der Diluviale Mensch von Krapina in Kroatien" 1906, were largely used, together with certain other measurements, such as the estimate for total height, etc. For the use of the casts and the assembling of data, together with kindly criticism, I am indebted to Dr. George Grant MacCurdy, Curator of Anthropology in this museum, while to Professor Joseph Barrell, who has taken a very lively interest in the work, I wish also to acknowledge my gratitude.

My conception of *Homo primigenius* is that of a man of low stature, standing only five feet three inches in height, but of great physical prowess as indicated by the robustness of the limb-bones and especially of their articular ends. The great paunch of the higher anthropoid apes, which are almost exclusively vegetarians, is lacking and in its place is shown the clean-cut, athletic form of torso such as one sees in the typical North American Indians, for I imagine food conditions were much the same. We have abundant evidence that Paleolithic man was a crafty hunter, for the remains of various animals which he slew for food are found in the bone breccias of the caverns wherein his own relics are entombed. Great power is indicated, however, in the upper portion of the trunk and in the arms, compensating this ancient type for his lack of adequate tools and weapons.

The knees are somewhat flexed as the curved thigh bone would indicate, and probably should be more so, and the trunk is only partially erect, for the inward curves of the back bone, so characteristic of modern man, are but feebly developed, as in the case of babes of the present day or in individuals bowed down by the weight of years. The shin is relatively short, as with certain present-day races, and the great toe somewhat offset though having long since lost its ape-like opposability.

The head shows the prominent supra-orbital ridges above the deep-set eyes; the low, flat forehead; the broad, concave, nasal bridge and the somewhat prognathous jaws. The lower jaw is deep and powerful, and lacks the characteristic chin prominence of modern man. Other restorations give a greater prognathism than mine, and it may be that here I am in error in showing too great a refinement of countenance as compared with the low type of calvarium. The contour of the jaw is based upon actual measurement of one of the Krapina specimens and one should bear in mind that the far older jaw recently brought to light at Heidelberg, though of a more brutal type than any yet known, shows less dental prognathism than do the modern negroes, indicating a very great antiquity for the radiative evolution of the several human stocks.

In all probability the men of that day were much more hairy than the model would indicate, as they had little or no clothing and the climate, during part of their racial career at least, was severe. They were, however, cave dwellers and knew the use of fire. I have purposely refrained from indicating this conjectural character, as it would, to a certain extent, conceal the conformation of the underlying parts.

A jaw of the cave bear, *Ursus spelæus*, a contemporary animal, though now long since extinct, is borne in the left hand, while the right contains a chipped stone implement from one of the typical stations, thus indicating the cultural plane of the race.

This type dwelt in Europe before the last glacial period, estimated at from 100,000 to 200,000 years ago, and continued for a long period of time, for his remains are found entombed successively with both cold and warm climate animals. The relics are found within or near rock shelters and caves, the best known of which are those of Neanderthal, Germany; Spy, Belgium; Krapina, Croatia; Le Moustier and La Chapelle-aux-Saints in France. As a race *Homo primigenius* is to-day entirely extinct, though whether he was blotted out or absorbed by the invading horde of the superior *Homo sapiens* we have no certain knowledge. Occasionally, however, something of his type appears in modern man, notably in St. Mausberg, a medieval Bishop of Toul, and in Lykke, a scientific Dane of the eighteenth century, as well as among Austrians and Melanesians, the lowest living races of mankind. These may be looked upon as instances of atavistic reversion.

The "Man of Spy," while showing more pithecoïd characters than his successor, was nevertheless eminently human, representing as he does the type just preceding modern man, and one far removed from a true ape-like ancestry. In the popular conception "Prehistoric man" should be gorilloïd, or at any rate distinctly simian; against this misconception the model stands as a silent protest.



RESTORATION OF PALEOLITHIC MAN.



ART. XII.—*Bismite*; by W. T. SCHALLER and  
F. L. RANSOME.

IN the Goldfield district in Nevada, bismite occurs in the January, Combination, Sandstorm, and probably also in other mines, as minute, pearly scales with brilliant luster and of silvery whiteness. The luster of the scales is almost metallic and suggests at first glance delicate and untarnished crystals of native silver. The mineral is limited to the oxidized zone, is usually accompanied by limonite and is frequently associated with rich ore. It occurs as single glittering scales or specks on the walls of cavities in spongy limonite or rusty ledge-matter, as delicate frost-like films on the same materials and as spongy aggregates with quartz. In the last-named form it is clearly pseudomorphous after bismuthinite, the material having consisted originally of a mass of bismuthinite prisms held together by a siliceous gangue. The prismatic structure of the bismuthinite is retained as hollow casts in the quartz, lined or partly filled with scales of bismite.

As natural crystals of bismite do not appear to have been found hitherto and as the mineral has been assigned to the orthorhombic system in Dana's and Hintze's mineralogies on the basis of Nordenskiöld's work on artificial crystals in 1860 and 1861, considerable interest attaches to the Goldfield occurrences on account of the crystallinity of the material.

When examined under the microscope in gently powdered material the crystals appear as thin colorless scales, with occasionally a suggestion of hexagonal outline. On account of their tenuity, it is rare that an edge view of a scale is obtainable. The larger flat-flying scales are dark in all positions between crossed nicols and give a negative uniaxial figure with convergent light. There are no colored rings and the double refraction is apparently not great. The refractive index, on the other hand, is rather high, being greater than that of anorthite. The mineral has a perfect basal cleavage and the scales, viewed without the analyzing nicol, commonly show delicate interference colors due to the refraction and reflection at the surfaces of the exceedingly thin cleavage sheets.

Some of the best material obtainable was analyzed with results as follows:

Insol. in HCl, mostly	1	2	3	Average
quartz gangue .....	78.95	78.87	79.01	78.94
Bi <sub>2</sub> O <sub>3</sub> .....	17.29	17.00	16.84	17.04
H <sub>2</sub> O (loss on ign.) .....	3.96	----	----	3.96
Fe <sub>2</sub> O <sub>3</sub> .....	0.36	0.50	0.21	0.36
				100.30

The results show that the mineral is either bismite or else a hydrous oxide of bismuth. If the latter be the case, the mineral is a new species (providing, of course, that  $\text{Bi}_2\text{O}_3$  is the correct formula for the bismuth ocher found in nature and called bismite). Attempts to isolate a sufficient quantity of the pearly scales from the gangue for separate analysis were not successful.

The minute, tabular crystals are too incomplete to allow of a determination of their geometrical form by crystallographic measurements alone. From the uniaxiality of the crystals, their hexagonal outline, triangular markings on the base and distribution of the faces as far as seen, reference of them to the rhombohedral division of the hexagonal system appears to be justifiable.

The value of the  $c$  axis, derived in a manner presently to be described, is 0.5775. Seven faces are determined as present; the base, five positive and one negative rhombohedra. Besides these, there are indications of two more positive rhombohedra. A brief description of these forms follows.

$c$  {0001}. Always very large, even, and highly polished. Sometimes shows triangular markings or striæ, the faces parallel to these markings being taken as positive.

$o$  {1016}. Occurs on two crystals, as broad faces giving, however, poor reflections. One face was considerably striated, giving two signals a degree apart.

$q$  {1015}. Broad faces giving fairly good reflections.

$u$  {1014}. Narrow faces, one striated with a fair reflection, and one as a line face giving a very poor reflection.

$k$  {1013}. Usually as a line face, striated and giving a very poor reflection.

? {2025}. A doubtful face, narrow, giving no distinct signal.

?  $d$  {1012}. Another doubtful face, broad, giving no distinct reflection.

$y$  {2021}. Line faces, giving exceedingly faint reflections.

$z$  {0111}. The only negative rhombohedron observed. Very faint line faces, giving no reflection. Its negative position could be determined only on crystal No. 6.

The measurement of the forms are shown below.

		Meas.	Calc.
(0001) :	(1016)	6° 37'	6° 41'
" :	(1015)	7 33	7 36
" :	(1014)	9 31	9 31
" :	(1013)	12 11	12 26
		13 18	12°-14°
" :	(2021)	54°	54°
" :	(0111)	35°	32½°
			53 08
			33 42

Doubtful forms:	Meas.	Calc.
(0001) : (20 $\bar{2}$ 5),	15°	14° 56'
" : (10 $\bar{1}$ 2),	16°–20°	18 26

The value for the  $c$  axis was obtained from three measurements that were considered as the most accurate. The others gave values agreeing fairly well with the one adopted, as is shown below. The crystals were measured on the two-circle goniometer and the  $\rho$  angle for these forms is the angle between that form and the base.

The three best measurements are:

$\rho \{10\bar{1}5\} = 7^\circ 33'$	$p_o = .6627$	cryst. No. 1
$\rho \{10\bar{1}5\} = 7 \ 36$	" = .6672	" " 4
$\rho \{10\bar{1}4\} = 9 \ 31$	" = .6706	" " 2

$$\text{Av. } p_o = .6668 ; c = 0.5775.$$

An average of the other measurements gave values closely agreeing. Thus:

$\rho \{10\bar{1}6\} = 6^\circ 37'$	$p_o = .6960$	cryst. No. 3
" = 6 41	" = .7031	" " 6
$\rho \{10\bar{1}4\} = 9 \ 31$	" = .6706	" " 6
$\rho \{10\bar{1}3\} = 12 \ 11$	" = .6477	" " 6
" = 12 26	" = .6614	" " 4
" = 13 18	" = .7102	" " 1

$$\text{Av.} = .6815$$

The following measurements of faces giving no distinct reflections also showed close agreement:

$\rho \{10\bar{1}3\} = 12^\circ\text{--}14^\circ$ (av. $13^\circ$ )	$p_o = .69$	cryst. No. 1
$\rho \{20\bar{2}5\} = 15^\circ$	" = .67	" " 2
$\rho \{10\bar{1}2\} = 16^\circ\text{--}20^\circ$ (av. $18^\circ$ )	" = .65	" " 1
$\rho \{01\bar{1}1\} = 35^\circ$	" = .70	" " 5
" = $32\frac{1}{2}^\circ$	" = .64	" " 6
$\rho \{20\bar{2}1\} = 54^\circ$	" = .69	" " 1
" = $54^\circ$	" = .69	" " 6

The values for  $p_o$  just given show that the interpretation of the forms is the correct one.

Of the six crystals (all incomplete) that were measured, only two need to be briefly described.

Fig. 1a is an orthographic projection of a crystal (No. 1), showing the trigonal distribution of the rhombohedra, and the triangular markings on the base.

Fig. 1b shows a similar projection of cryst. No. 6, with a negative rhombohedron.



An odd feature of these crystals is that the development of the faces is so uneven, that no two faces of the same form are present on the upper half of a crystal, though this is in part due to the incompleteness of each crystal.

From the foregoing observations it appears that the natural bismite is not orthorhombic but belongs to one of the uniaxial

FIG. 1a.

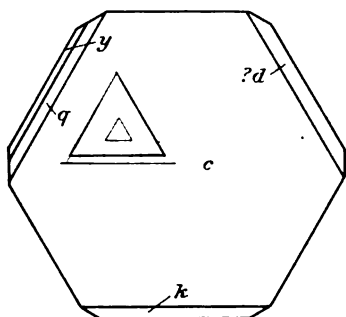
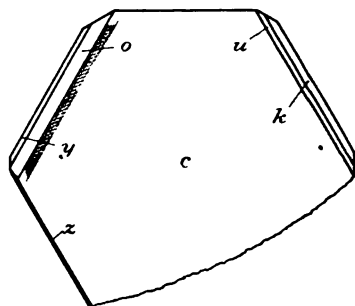


FIG. 1b.



systems, probably the hexagonal. Its presence in oxidized ore appears to be uniformly indicative of bismuthinite in the original sulphide ore. Some migration, however, has taken place during oxidation and the scales of bismite do not always occupy the exact positions of the parent needles of bismuthinite.

U. S. Geological Survey,  
Washington, D. C.

ART. XIII.—*Contributions to the Mineralogy\* of Franklin Furnace, N. J.*; by CHARLES PALACHE.

THE purpose of this paper is to present in brief form some of the more interesting results obtained in the study, continued through several years, of the minerals of Franklin Furnace, New Jersey. The complete results of the study will, it is hoped, appear soon in monograph form, but it seems desirable to place on record without further delay the chemical analyses made for the most part in the laboratory of the Geological Survey. These analyses are either of minerals not before recorded from this locality or of species concerning which our information is incomplete. With these are also included crystallographic notes on a number of species and a list of additional minerals whose presence at Franklin Furnace has not hitherto been recorded.

*Arsenopyrite: Crystal Form, Composition.*

Brilliant crystals of arsenopyrite up to an inch in length were found in several of the limestone quarries at Franklin Furnace in 1905. They are associated with pyrite, pyrrhotite, spinel, humite, tourmaline and phlogopite. The crystals are completely developed, showing besides known forms the new pyramids (532), (112), (143), and (132), the first present on all crystals and characteristic for the locality.

The following analysis by E. C. Sullivan, U. S. G. S., was made of selected crystal fragments:

		Ratio	
Fe.....	32.48	.581	} 1
Co.....	1.16	.02	
As.....	48.72	.650	1.08
S.....	18.80	.587	.98

The ratio shows a normal composition. The presence of cobalt is interesting; it has been shown by Kraus & Scott† to be present in about the same proportion in pyrite crystals in the same limestone. Tests for cobalt made on the associated pyrrhotite showed no trace of this element and hardly more than a trace of nickel.

*Fluorite: Composition.*

The following analysis of fluorite by G. Steiger, U. S. G. S., was made in the belief that it was a manganiferous variety.

\* Published by permission of the Director of the U. S. Geological Survey.

† *Zeitschr. für Kryst.*, xliv, 144, 1907.

The material was pale red and granular, the matrix of franklinite grains.

Ca .....	51.21	Al .....	0.18
Mg .....	0.24	F .....	45.85
Fe .....	0.27	Cl, Co, ....	none
Mn .....	0.09		
			<hr/> 97.84

Mr. Steiger remarks that the deficiency in the analysis is doubtless due to fluorine.

The manganese content is insignificant. If the total deficiency, 2.16 per cent, is calculated as fluorine, there is still slightly less than is required to form  $RF_2$  with all bases, but almost exactly enough to satisfy the calcium. This suggests, but of course does not prove, that the bases other than calcium are present as impurities in the form of unknown compounds.

*Manganosite: Occurrence, Composition.*

This rare substance, known hitherto only from two Swedish localities, was found in a single specimen in the Harvard Mineralogical Museum. The specimen consists of a granular aggregate of franklinite, zincite and manganosite. The latter is in irregular grains showing cubic cleavage, dark green in the mass, emerald-green in thin fragments. The material analyzed contained traces of zincite and minute black films of manganese oxide. The specific gravity was 5.364.

1. Manganosite: analysis by George Steiger, U. S. G. S.
2. Same corrected for  $ZnO$  and  $MnO$ , known to be present.

	1	2
MnO .....	94.59	99.61
MnO <sub>2</sub> .....	1.30	----
ZnO .....	3.41	----
FeO } .....	0.26	0.27
Fe <sub>2</sub> O <sub>3</sub> }		
MgO .....	0.11	0.12
H <sub>2</sub> O - .....	0.38	----
H <sub>2</sub> O + .....	0.40	----
	<hr/> 100.45	<hr/> 100.00

The material is thus shown to be very nearly of the theoretical composition of manganosite,  $MnO$ .

*Zincite: Crystal Form.*

Measurements of natural crystals of zincite are very few and poor and the generally accepted axial ratio for the species is based on artificial crystals. The writer obtained measurements

on one crystal of zincite from Franklin Furnace, however, which were very satisfactory; he has therefore calculated an axial ratio based on them and in the following table gives all the measurements made on natural crystals and the corresponding angles calculated from (1) the new ratio, (2) Dana's ratio, (3) Traube's ratio based on artificial crystals. The author's measurements were on four faces of the pyramid (4045), the angle to the base (average) being  $55^{\circ} 42'$  with deviation of but  $\frac{1}{4}^{\circ}$ . A single reading (0001) to (10 $\bar{1}$ 1) was also obtained, in close agreement.

Angle	Calculated			Measured				
	Dana a:c= 1:1.6219	Traube a:c= 1:1.6077	Palache a:c= 1:1.5870	Dana '86	Grosser '92	Moses '95	Palache	
							Contact	Reflexion
0001 $\wedge$ 10 $\bar{1}$ 1	61°54'	61°41'	61°23'	----	----	----	62°00'	61°22'
10 $\bar{1}$ 1 $\wedge$ 01 $\bar{1}$ 1	52 21	52 14	52 04	----	----	----	52 00	* ----
0001 $\wedge$ 4045	56 17	56 03	55 42	----	55°38'	55°40'	----	55°42'
4045 $\wedge$ 0445	49 09	49 00	48 48	----	48 50	----	----	----
0001 $\wedge$ 5054	66 52	66 41	66 25	65°20'	----	----	----	----
5054 $\wedge$ 0554	54 46	54 40	54 33	53 53	----	54°42'	----	----

*Gahnite, variety Dysluite: Composition.*

Following is an analysis of a gahnite crystal supplied by Mr. Canfield from the locality at Sterling Hill which yielded the enormous crystals in the Canfield Collection. This is the type of the variety dysluite but has not been before analyzed. Specific gravity 4.56.

1. Analysis of dysluite, W. T. Schaller, U. S. G. S., 1906.

2. Same omitting SiO<sub>2</sub>, CO<sub>2</sub>, and equivalent of CaO, and H<sub>2</sub>O. State of oxidation of iron and manganese not known.

	1	2	Mol. Ratio	
Al <sub>2</sub> O <sub>3</sub> .....	47.27	48.81	.478	} .542 = 1
Fe <sub>2</sub> O <sub>3</sub> .....	9.90	10.22	.064	
ZnO .....	37.10	38.31	.472	
MnO .....	0.93	0.97	.013	} .523 = 1.04
MgO .....	1.09	1.12	.028	
CaO .....	1.01	0.57	.01	
CO <sub>2</sub> .....	0.38	----	----	
SiO <sub>2</sub> .....	1.47	----	----	
H <sub>2</sub> O .....	1.21	----	----	
	100.36	100.00		

The composition of dysluite is very like that of the gahnite from Franklin Furnace analyzed by Brush, both being very high in zinc.

*Franklinite: Form, Composition.*

Small implanted crystals of franklinite of quite abnormal appearance were seen in two specimens believed to have come from the Hamburg mine, Franklin Furnace. The crystals are of adamantine luster and on edges or where splintered show a deep red color. The prevailing habit is cubo-octahedral with occasional planes of the forms (101), (311), (211) and (310). The unique color and habit of these crystals suggested a new type of the spinel group, but the analysis below by W. T. Shaller, U. S. G. S., shows them to be of ordinary franklinite composition. Specific gravity 5.09.

*Fe <sub>2</sub> O <sub>3</sub> .....	66.58	CaO.....	0.43
*MnO.....	9.96	MgO.....	0.34
ZnO.....	20.77	H <sub>2</sub> O.....	0.71
			<hr/>
			99.51

*Heterolite: Form, Composition.*

Reëxamination of this mineral, which has been a doubtful species because of Moore's incomplete description, establishes the correctness of his characterization as a zinc hausmannite.

Tetragonal, shown by optical behavior of the fibers under the microscope. Indistinct prismatic cleavage, specific gravity 4.85.

Composition ZnO.Mn<sub>2</sub>O<sub>3</sub>, as shown by the following analysis of material furnished by E. P. Hancock:

1. Heterolite, analysis by W. T. Schaller, U. S. G. S., 1906.

2. Same corrected for the small amount of SiO<sub>2</sub> and for water probably contained in a slight admixture of chalcophanite.

	1	2	Ratio.
Mn <sub>2</sub> O <sub>3</sub> .....	60.44	63.85	.405
Fe <sub>2</sub> O <sub>3</sub> .....	.77	0.83	.005
ZnO.....	33.43	35.32	.435
SiO <sub>2</sub> .....	1.71		
H <sub>2</sub> O—.....	2.47		
H <sub>2</sub> O+.....	1.42		
	<hr/>	<hr/>	
	100.24	100.00	
	Hausmannite,	MnO.Mn <sub>2</sub> O <sub>3</sub>	
	Heterolite,	ZnO.Mn <sub>2</sub> O <sub>3</sub>	

*Pyroxenes: Composition.*

Manganese- and zinc-bearing varieties of pyroxene are characteristic both of the granite and of the intruded rocks near the contacts at Franklin Furnace and Stirling Hill. The dis

\* State of oxidation of iron and manganese not known.

inctions between these pyroxenes are not sharply defined. Jeffersonite, the most abundant of them, contains manganese zinc and iron in addition to lime and very little magnesium. Zinc schefferite differs in the practical absence of iron and in the increase of calcium and magnesium at expense of manganese and zinc. Schefferite, close to the last named, contains no zinc, little iron and a larger proportion of magnesium. Schefferite was found only in well-defined crystals in limestone from Stirling Hill. The analyses here given are of a very fresh jeffersonite from Parker shaft, Franklin Furnace, and of schefferite which has not been before described from this region.

1. Analysis of jeffersonite, Steiger, U. S. G. S., 1906.

2. Analysis of schefferite, Schaller, U. S. G. S., 1907.

SiO <sub>2</sub>		CaO		MgO		MnO		ZnO		FeO		Al <sub>2</sub> O <sub>3</sub>		Fe <sub>2</sub> O <sub>3</sub>		H <sub>2</sub> O—		H <sub>2</sub> O+		Na <sub>2</sub> O		CO <sub>2</sub>	
1	49.03	19.88	5.81	7.91	7.14	3.95	0.86	4.23	0.60	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
2	49.80	21.07	12.35	9.69	tr.	1.61	0.26	1.46	1.55	1.81	0.9	0.43											
[F = 0.81 = 99.93 less .13 = +																							

#### *Nasonite: Crystal Form.*

The crystal form of nasonite could not be determined by Penfield in the absence of crystals, but he concluded that it was tetragonal because of chemical analogy with ganomalite—a tetragonal mineral.

Crystals of nasonite were intrusted to the writer by Mr. Canfield, who had recognized their hexagonal character. One of them proved measurable and showed the forms  $a$  (11 $\bar{2}0$ ),  $m$  (10 $\bar{1}0$ ),  $p$  (10 $\bar{1}1$ ) and  $x$  (90 $\bar{9}2$ ), the hexagonal symmetry being well defined. The axial ratio, based on two measurements of angle  $c \wedge p = 56^\circ 40'$ , is  $a:c = 1: 1.3167$ .

Angle  $c \wedge x$ , calculated  $81^\circ 41'$ , measured  $81^\circ 36'$ .

The faces of  $m$  are cavernous except at the prism edges, where they are well defined and generally truncated by  $a$ . The prism rounds over into the pyramid  $p$  on most of the small crystals seen, the form  $x$  representing a plane face  $t$  in this surface on one crystal. The faces of  $p$  were dull on all except the measured crystal. This was afterwards tested qualitatively and gave the reactions of nasonite.

#### *Glaucochroite: Crystal Form.*

Terminated crystals were not present in the original specimens of glaucochroite described by Penfield, but he obtained an approximate axial ratio by measurement of the inclination of individuals in twin position.

Two terminated crystals were secured from a specimen loaned by the Foote Mineral Co. which yielded fair measurements, determining the following axial ratio and forms.

$$a : b : c = .4409 : 1 : .5808 \\ = .440 : 1 : .566 \text{ (Penfield).}$$

Forms : *a* (100), *b* (010), *m* (110), *s* (120), *x* (103), *h* (021)  
*e* (111), *f* (121).

Combinations : 1. *b. m. s. x.*

2. *a. b. m. s. k. e. f.*

Angles :	Calculated		Measured		
	$\phi$	$\rho$	$\phi$	$\rho$	
111	66° 12'	55 13	66 13	55 15	2 faces good
121	48 36	60 12	49 22	60 29	1 face poor
110	69 12	90 00	66 09	90 00	4 faces good
120	48 36	90 00	49 14	90 00	poor

### *Bementite: Composition, System.*

The description of bementite by Koenig was incomplete and its relations were not clear. Study of a later find of better material from the Parker shaft, Franklin Furnace, establishes its close relationship to tephroite in system and composition.

System orthorhombic, shown by three pinacoidal cleavages at right angles but unequally perfect; and by a symmetrical biaxial interference figure with small axial angle seen on plates parallel to the best cleavage.

The analysis given below agrees closely with that of Koenig, but the water is shown to be constitutional, coming off for the most part at a red heat. It leads to the formula  $H_2Mn_2(SiO_4)_2$ , with more or less replacement of manganese by iron, zinc and magnesium. This is analogous to the formula of tephroite, which may be written  $Mn_2Si_2O_{10}$ ; in bementite three molecules of manganese are replaced by constitutional water. That it is not a simple case of partial hydration is shown by the optical homogeneity of the bementite crystals.

1. Analysis of bementite, Geo. Steiger, U. S. G. S., 1906.

2. Same recalculated to 100 per cent after omitting  $Al_2O_3$ ,  $Fe_2O_3$ , and  $H_2O$ —and substituting for  $FeO$ ,  $MgO$ ,  $CaO$ , and  $ZnO$ , equivalent amounts of  $MnO$ .

3. Theory for  $H_2Mn_2(SiO_4)_2$ .

	$SiO_2$	$MnO$	$FeO$	$ZnO$	$MgO$	$CaO$	$H_2O +$	$H_2O -$	$Al_2O_3$	$Fe_2O_3$	
1	38.36	39.22	4.94	2.93	3.35	0.62	8.01	0.60	0.96	0.71	99.70
2	37.93	53.56					8.51				100.00
3	37.18	54.53					8.29				100.00

### *Willemite: Axial Ratio, Refractive Indices.*

No accurate measurements of willemite crystals from New Jersey have been hitherto recorded. The fundamental angle employed by Dana was based on contact measurements of troostite. Other authors use the element determined by Lévy on crystals from Moresnet, on which the sole form is a rhombohedron not found on Franklin crystals. A number of measurable crystals, all from the Parker shaft, Franklin Furnace,

passed through the writer's hands and the data secured from them permit the establishment of a satisfactory axial ratio. The five measured crystals were colorless or pale green prisms terminated by the base and one or both of the rhombohedrons  $e(01\bar{1}2)$  and  $r(10\bar{1}1)$ .

Angle  $c \wedge e$ , 19 readings average  $20^\circ 47'$ , limits  $20^\circ 35' - 21^\circ 04'$   
 "  $c \wedge r$ , 14 " "  $37^\circ 35'$ , "  $37^\circ 20' - 37^\circ 40'$

Whence  $a : c = 1 : 0.6612$

Lévy " =  $1 : 0.6696$

Dana " =  $1 : 0.6775$

Calculated angle,  $c \wedge e = 20^\circ 53'$

" "  $c \wedge r = 37^\circ 22'$

Refractive indices, measured on a prism  $\parallel c$ .

Sodium light,  $\omega = 1.69390$   $\epsilon = 1.72304$

Lithuim "  $\omega = 1.68897$   $\epsilon = 1.71812$

*Friedelite: Occurrence; Composition.*

Friedelite has not been before described from America. It was identified by the writer on a single specimen from Buckwheat mine, Franklin Furnace, in the Kemble Collection, and in minute amount on specimens from the Parker shaft. The mineral occurs in scales or tabular crystals with the unit rhombohedron and base, not measurable.

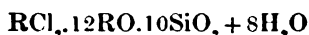
The analysis, with others for comparison, follows:

1. Friedelite, Franklin Furnace, Schaller, U. S. G. S., 1906.
2. Same recalculated to 100 per cent after removing  $H_2O$ —and substituting equivalents of  $MnO$  for  $FeO$ ,  $MgO$ ,  $ZnO$  and  $CaO$ .
3. Average of four analyses of friedelite (Dana, System and 1st Appen.) recalculated as in number 2 above.
4. Theory for  $H_{10}(MnCl)_2Mn_2(SiO_4)_2$ .
5. Theory for  $H_{10}(MnCl)_2Mn_2Si_{10}O_{22}$ .
6. Theory for  $H_{10}(MnCl)_2R_{10}Si_{10}O_{22}$  (Zambonini).

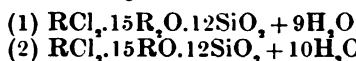
	1	2	3	4	5	6
SiO <sub>2</sub>	34.69	34.95	34.14	34.73	34.43	34.84
MnO	48.00	53.22	54.35	54.80	54.33	53.60
Cl	3.43	3.45	3.42	3.42	3.39	4.12
H <sub>2</sub> O +	9.08	9.15	8.84	7.82	8.60	8.36
H <sub>2</sub> O —	1.94					
FeO	1.45					
MgO	.98					
ZnO	1.05					
CaO	.63					
	101.25	100.77	100.75	100.77	100.75	100.92
Less O = Cl	.77	.77	.75	.77	0.75	.92
	100.48	100.00	100.00	100.00	100.00	100.00



The Franklin friedelite agrees closely in composition with that of other localities, as shown by comparison of columns 2 and 3. Groth's formula for the mineral, used by Dana, does not well express the results of these analyses, which uniformly give a higher content of manganese or its equivalents and a lower content of chlorine than demanded by it. The formula adopted here,  $H_2(MnCl)Mn_2(SiO_4)_2$ , is satisfactory as to all constituents save water, for which it is too low. The formula  $H_{2.5}(MnCl)_2Mn_{1.5}Si_2O_{10}$ , obtained by adding one-half molecule of water to the latter, comes nearest to the exact equivalent of the analytical data but was rejected as not being reducible to the orthosilicate form. Zambonini\* has derived for pyrosmalite and friedelite the formula



an expression which takes no cognizance of the fact that the water in these minerals is combined. The above formulas, reduced to this form of expression, are:



This formula of Zambonini gives a composition very similar to (2) and quite as close to the analytical results except for chlorine, which is too high. It is better than (1) as to water but is no closer in regard to other constituents.

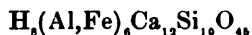
*Vesuvianite, variety Cyprine: Analysis.*

Bluish green fibrous vesuvianite corresponding in character with the Norwegian cyprine was found in 1905 in granite from the Parker shaft. The material was carefully freed from minute specks of metallic copper and had a specific gravity of 3.451. The analysis by Steiger, U. S. G. S., 1907, follows:

SiO <sub>2</sub>	36.41	PbO	trace
Al <sub>2</sub> O <sub>3</sub>	17.35	Na <sub>2</sub> O	0.44
Fe <sub>2</sub> O <sub>3</sub> }	1.86	K <sub>2</sub> O	0.50
FeO }		H <sub>2</sub> O—	0.24
MgO	1.38	H <sub>2</sub> O +	3.51
MnO	1.75	F	0.36
ZnO	1.74		
CuO	1.85		100.23
CaO	33.21	less O = F	0.17
		Sum	100.06

This analysis agrees closely with that of the cyprine from Tellemarken save in the greater amount of water and less fluorine. It corresponds to the formula:

\* Zeitschr. Kryst., xxxiv, 554.



with part of the lime replaced by a number of oxides.

*Datolite: Crystal Form.*

Datolite has been known for some time from the Parker shaft, Franklin Furnace, but crystals have not hitherto been described from there. Complex crystals were found in a specimen in the Harvard Collection on which were observed a number of forms including several new to the species. In the following list new forms are marked with an asterisk :

$a$  (001)  $e$  (023)  $x$  (101)  $\gamma$  (221)  $\epsilon$  (111)  $f$  (241)  $k$  (245)  
 $c$  (100)  $M$  (011) \* $I$  (304)  $\Lambda$  (111)  $\alpha$  (221)  $j$  (243)  
 $g$  (110)  $o$  (021)  $\phi$  (102)  $\theta$  (112)  $Q$  (121) \* $d$  (263).  
 $m$  (120) \* $q$  (701)  $\zeta$  (101)  $Y$  (223)  $\mu$  (211) \* $k$  (475)

Symbols and letters after Goldschmidt, Winkeltabellen.

The pyramid  $d$  (263), new to datolite, is present on all the crystals with characteristic form.

*Cuspidine: Occurrence; Composition.*

The occurrence of this mineral, known hitherto solely from Vesuvius, at Franklin Furnace is established by the following analysis, for which the writer is indebted to Dr. C. H. Warren.

The material, which occurred with nasonite, was isolated by hand-picking and heavy solution and analyzed by him at the time (1899) Penfield and Warren were working on nasonite and other peculiar silicates from the Parker shaft. At the time no satisfactory interpretation of the analysis was hit upon, the identity of the mineral remained hidden, and, all the material having been used in analysis, the matter was put one side. The material analyzed consisted of glassy white crystal fragments of specific gravity between 2.965 and 2.989.

I. Analysis of cuspidine, C. H. Warren, 1899.

II. Same recast and recalculated to 100 per cent after substituting equivalents of Ca for Mn, K, and Na.

I		II		Molecular Ratio	
SiO <sub>2</sub>	32.36	Si	15.10	.539	1
CaO	61.37	Ca	44.63	1.115	2.05
MnO	0.71	F	9.05	.238	} 2.189
Na <sub>2</sub> O	0.48	O	31.22	1.951	
K <sub>2</sub> O	0.27				4.06
F	9.05				
	104.24				
Less O = F,	3.81				
	100.43				

The ratio  $\text{Ca} : \text{Si} : (\text{O} + \text{F}_2) = 2 : 1 : 4$  very nearly, leading to the formula  $\text{Ca}_2\text{Si}(\text{O}, \text{F}_2)_4$ . This is the formula suggested by Dana (System, 529) for cuspidine, in which fluorine is treated as replacing oxygen. No other treatment of the analytical data gave a satisfactory ratio. It is much to be regretted that no further material remains for more complete physical determination of this interesting species.

*Humite: Crystal Form.*

Minerals of the humite group have long been known from Franklin under the name of chondrodite. They have not been analyzed nor till recently have good crystals been found. In 1906 were found orthorhombic crystals of deep orange-red and pale yellow color which yielded contact measurements accurate enough to prove the material to be humite.

Forms :  $b$  (010),  $o_2$  (210),  $m$  (110),  $e_\delta$  (102),  $n_a$  (112),  $r_1$  (214).

Combinations :

1.  $b, o_2, n_a, r_1$ .
2.  $b, o_2, e_\delta, n_a, r_1$ .
3.  $b, o_2, m, e_\delta, n_a, r_1$ .

*Leucophœnicite: Crystal Form.*

Leucophœnicite was described by Penfield, whose material did not permit him to determine the system to which the crystals belong. From its relation in composition to the humite group he believed it to be monoclinic.

Crystals of measurable quality very kindly placed in the writer's hands by Mr. Canfield, furnished data for the determination of system and forms.

System, monoclinic:—Axial ratio :  $a : b : c = 1.1045 : 1 : 2.3155$ .  
 $\beta = 76^\circ 44'$ .

Forms :

$c$ (001)	$s$ (120)	$x$ (103)	$y$ ( $\bar{1}03$ )	$l$ (121)	$d$ (123)
$b$ (010)	$e$ (101)	$r$ ( $\bar{1}01$ )	$o$ (011)	$n$ ( $\bar{1}21$ )	$h$ ( $\bar{1}23$ )
$a$ (100)	$f$ (102)	$i$ ( $\bar{1}02$ )	$f'$ (012)	$u$ ( $\bar{1}22$ )	$q$ ( $\bar{1}24$ )
$m$ (110)					

The crystals are of epidote habit, elongated parallel to the  $b$ -axis, the orthodome zone deeply striated. Crystals are twinned on a face in this zone which was taken as the basal pinacoid, the two individuals frequently interpenetrating. The form series is peculiar and could not be correlated in any way

with that of any member of the humite group to which leuco-phœnicite is related chemically.

The presence at Franklin Furnace or at Stirling Hill of the following minerals, not hitherto recorded, has been established: Marcasite, millerite, pyrrhotite, aurichalcite, hydrozincite, psilomelane, göthite, albite, chlorite, ganophyllite, manganese pectolite, descloizite, anglesite and native silver.

With these additions and the omission of a number of species of the older lists which could not be verified, the number of minerals recorded for this locality becomes ninety-three.

Harvard University, October, 1909.

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## SCIENTIFIC INTELLIGENCE.

### I. CHEMISTRY AND PHYSICS.

1. *The Formation of Colloidal Solutions by the Action of Ultra-violet light upon Metals.*—It was observed by Lenard and Wolf in 1889 that certain substances, particularly metals, were resolved to dust by the action of ultra-violet light. This effect was detected both by the roughening of the surfaces and the detection of the detached particles in the adjacent layers of air. It was found that different metals gave different degrees of this action, that the electrical condition of the metallic plate exerted a pronounced influence upon the action, as did also the nature of the source of light employed. These investigators did not attempt the preparation of colloidal solutions by this means, but they observed, when experimenting with a zinc plate, that a layer of water held back the zinc dust. SVEDBERG has now made use of this phenomenon in preparing colloidal solutions of various metals in various liquids. He placed the metal, the surface of which must be freed from layers of oxide, in a shallow dish, placed the liquid upon it, and exposed it to the rays of a Heraeus' quartz-mercury arc lamp at a distance of a few centimeters. After a few minutes the liquid when examined by the ultra-microscope showed the characteristic appearance of a colloidal solution. Different metals and different liquids behaved very differently. Silver, copper, tin and lead gave colloidal solutions easily, while platinum, aluminium and cadmium showed little or no effect. The action with lead was particularly strong. When water was used this metal gave a milky liquid in five minutes, probably colloidal hydroxide, while with ethyl alcohol the same metal gave a colloidal metallic solution. Further experiments with lead and silver in water and six different organic liquids indicated that

the size of the particles is very different in the various cases, and that this depends upon the nature of the liquid employed. It was especially interesting to find that it was possible to produce solutions with particles of very small, uniform size which displayed the Brownian movements in a very lively manner. Further study of this matter, which the author is undertaking, promises to be of great interest, and he suggests that it may be of importance in explaining the mechanism of common photochemical reactions.—*Berichte*, xlii, 4377. H. L. W.

2. *Potassium Percarbonate*.—Much uncertainty has arisen in regard to the true constitution of the product prepared in 1897 by Constam and von Hansen by the electrolysis of concentrated potassium carbonate solutions to which the percarbonate formula,  $K_2C_2O_6$ , was ascribed by the discoverers. Up to the present time this product has always been obtained in an impure condition, containing carbonate, bicarbonate and water, and since it yields hydrogen peroxide and potassium carbonate when dissolved in water, it has been possible to regard it as potassium carbonate with hydrogen peroxide of crystallization, instead of a true percarbonate. Moreover Tantar has obtained a well crystallized product by the combination of sodium carbonate and hydrogen peroxide, to which he gave the formula  $Na_2CO_3 + \frac{1}{2}H_2O_2 + H_2O$ , regarding it as a percarbonate combined with both hydrogen peroxide and water.

RIKSENFELD and REINHOLD have now succeeded in preparing the electrolytic product in a nearly pure anhydrous condition by the use of special precautions. The absence of hydrogen in this preparation proved that it was not a hydrogen peroxide addition product and analyses confirmed the formula  $K_2C_2O_6$ . They have also found a means for distinguishing between percarbonate and hydrogen peroxide in the fact that the former liberates iodine immediately from a neutral potassium iodide solution, while hydrogen peroxide acts only slowly upon such a solution. By means of this reaction they found that Tantar's product contains no percarbonate, so that its formula should be given as  $Na_2CO_3 + \frac{1}{2}H_2O_2$ .—*Berichte*, xlii, 4377. H. L. W.

3. *A Practical Application of Radium*.—In connection with a research on a revision of the atomic weights of iodine and silver, BAXTER and TILLEY found it necessary to determine small quantities of water in the iodine pentoxide which they were analyzing. This water was absorbed and weighed in glass U-tubes containing phosphorus pentoxide. The usual difficulty in weighing glass apparatus, due to electrical disturbance from wiping it, was avoided here by placing in the balance a few milligrams of radium bromide of radio-activity 10·000 to dispel electrical charges. Under these conditions no difficulty was experienced in weighing the tubes within a few hundredths of a milligram, since they quickly came to constancy in the balance case and retained their weights unchanged for days at a time.—*Jour. Amer. Chem. Soc.*, xxxi, 212. H. L. W.

4. *Volumetric Determination of Selenious Acid.*—L. MARINO has devised a method for this purpose which he prefers to those previously in use. The solution of the selenious acid is made slightly alkaline with sodium hydroxide solution, then a specially prepared alkaline permanganate solution is added gradually, until after heating to boiling a strong violet color is permanent for 4 or 5 minutes. After cooling somewhat the liquid is acidified with dilute sulphuric acid, and an oxalic solution is run in until all the manganese dioxide has dissolved. Then, finally, the excess of oxalic acid is titrated with the permanganate solution. The test-analyses given show very satisfactory results. A special method is given for the removal of nitrates in order that this method may be applied.—*Zeitschr. Anorgan. Chem.*, lxx, 32. H. L. W.

5. *A Contract for Radium.*—It is stated on the authority of the London Times that a contract has recently been entered into between the British Metalliferous Mines (Limited) and Lord Iveagh and Sir Ernest Cassel for the supply of  $7\frac{1}{2}$  grams of pure radium bromide at the rate of four pounds per milligram (total about \$150,000). The source is pitchblende from the company's mine in Cornwall. This radium bromide is to be presented by Lord Iveagh and Sir Ernest Cassel to the Radium Institute, which will be under the direction of Sir Frederick Treves, for use in the treatment of cancer.—*Chem. News*, xci, 303. H. L. W.

6. *Absolute Measurement of High Pressure with the Amagat Manometer.*—PETER PAUL KOCH and ERNST WAGNER have described in a previous paper a method of measuring accurately high pressures which gave very satisfactory results; but in order to reach a higher degree of exactness they concluded to measure the pressures directly by a height of mercury. The tower of the Laboratory in Munich afforded a height of  $25^m$ , and they describe the arrangement of steel tubes by means of which they contained the mercury. A comparison is given of the results of the Amagat manometer, with the results obtained by direct measures, obtained from the height of the mercury column. A constant of correction is given.—*Ann. der Physik*, 1910, No. 1, pp. 31–50. J. T.

7. *A Relation Between Absorption and Phosphorescence.*—The observations of M. G. Lecoq de Boisfrandran and M. G. Urban show that the best known phosphorescent bodies result from a *phosphorogène* in a solvent or diluent. M. L. BRÜNINGHAUS points out a very simple relation between absorption and phosphorescence. The light emanating from the *phosphorogène* molecules situated in the depths of the medium suffer absorption by the superficial layers, and the radiations observed at the surface are only those for which the *phosphorogène* is relatively transparent.—*Comptes Rendus*, Dec. 13, 1909, pp. 1124–1129. J. T.

8. *Mass of Moving Electrons.*—The new theories of electrons are concerned with hypotheses of change of mass with velocity.

AM. JOUR. SCI.—FOURTH SERIES, VOL. XXIX, No. 170.—FEBRUARY, 1910.

Abraham supposes electrons unchanged by velocity, while the Lorentz-Einstein theory is based upon the relativity principle. E. HUPKA in his investigation endeavors to decide which theory is the most probable. The article is interesting principally from the view of technic : for the author describes minutely the method by means of which he excited electron streams in high vacua. Although he did not attain to the velocity of the  $\beta$  ray, he succeeded in producing rays of great homogeneity, suitable for measurement. The vacua were produced by liquid air and the use of charcoal, and he used potentials as high as 90,000 volts. The paper contains many tables and plotted charts, giving comparisons of results on the Abraham or solid sphere theory and the Lorentz-Einstein relativity principle. The measurements agree better with the latter theory than with the sphere theory of Abraham.—*Ann. der Physik*, 1910, No. 1, pp. 169–204.

J. T.

9. *Hertz's Photoelectric Effect*.—M. EUGÈNE BLOCH criticizes the conclusion that this effect coincides in greatness with the Volta series, the metals, more photoelectric, being the more electropositive, and believes that the order can be reversed when one passes from one wave length to another.—*Comptes Rendus*, Dec. 13, 1909, p. 1110.

J. T.

10. *Influence of Thunder on Size of Raindrops*.—V. J. LAINE has studied the changes in rainbows which apparently follow peals of thunder. He describes as follows a typical case : Between six o'clock and five o'clock in the evening he observed in the East a rainbow accompanied by a secondary bow. During thunder the colors of both bows trembled to such a degree that the color limits and the edges of the bows were entirely weakened, and one observed very quick vibrations over the entire rainbow. This occurred with each peal of thunder. The change in color Laine attributes to changes in size of raindrops. The size before peals of thunder was under  $0.1^{\text{mm}}$ , and during the thunder it increased to  $0.5^{\text{mm}}$  and to  $1^{\text{mm}}$ . The author attributes the change to the acoustical vibration of the thunder.—*Physikal. Zeitschrift*, Dec. 1, 1909, pp. 965–967.

J. T.

11. *Conduction of Electricity through Gases and Radio-activity*; by R. K. McCLUNG. Pp xvi + 245. Philadelphia, 1909. (P. Blakiston's Son & Co.)—This is a "text-book with experiments" designed to introduce college classes to the fascinating and important subjects indicated by the title. There has been so great a development during the past twelve years in our knowledge of the ionization of gases and the properties of the newly discovered radiations that ample material exists for an interesting and instructive course for students. The present book is the first to be written with this end in view, and it seems well adapted to the purpose. The descriptive portions though very concise are fairly satisfactory and many useful directions are given for performing experiments in this field.

H. A. B.

12. *Die Strahlen der positiven Elektrizität*; von E. GEHRCKE. Pp. xi + 124. Leipzig, 1909. (S. Hirzel).—This is an excellent and timely account of a class of radiations which have of late years come to be of great importance in physics. The rays which consist of positively charged particles include the canal rays discovered many years ago by Goldstein, certain other rays which are observed in ordinary vacuum tubes, the  $\alpha$ -rays from radioactive substances and the "anode rays" (recently discovered by Gehrcke and Reichenheim), which are given out by anodes consisting of the salts of various metals. The properties of all these rays and their accompanying phenomena are described in detail, and the book forms a very useful collection of data upon an important subject.

H. A. B.

## II. GEOLOGY AND NATURAL HISTORY.

1. *United States Geological Survey, Thirtieth Annual Report, 1908-1909, of the Director, GEORGE O. SMITH*. Pp. 128, with two plates.—This report contains a statement of the work done by the various divisions of the Survey during the fiscal year ending June 30, 1909. Besides the progress in geologic investigations and topographic mapping, for which the Survey was initially organized, the special lines of work which Congress has delegated to it are worthy of note. The classification of public lands has been carried forward with great activity, resulting in a proper valuation of land according to the use for which it is most valuable. As a consequence the government is deriving a revenue from the sale or lease of said lands many times greater than the cost of the surveys. Fraudulent entries are made more difficult and monopolistic control is prevented, but immediate utilization is fostered; the present system resulting in the greatest good to the nation at large.

The division of mine accidents has been organized within the year, studies have been carried on in Europe and in this country and already large results begin to show toward the prevention of the destruction of both human life and mineral resources.

The technologic branch by its investigations of materials used in government contracts has, during the year, guarded the expenditure of tens of millions of dollars and saved millions to the government.

Because these additions to the work of the Survey are so immediately important and popularly recognized as of great value, conscious effort should be maintained to prevent their encroachment upon the equally valuable purely scientific work upon which such developments ultimately rest. That Congress does not fully appreciate this broader view is shown by the fact that the Survey was only granted \$100,000 for stream measurements, whereas \$250,000 was appropriated for testing fuels. For topo-



graphic surveys \$300,000 was appropriated, for geologic surveys \$200,000, as during the previous year. The entire appropriation for the year was \$1,590,680.

J. B.

2. *Fifth Biennial Report. State Geological Survey of North Dakota*; A. G. LEONARD, State Geologist. Pp. 278, plates xxx. Bismarck, North Dakota.—The purposes of the reports of the survey are educational in the teaching of physical geography and elementary geology, and developmental of the economic resources of the state. In this volume, besides the administrative report, there are papers on the geology of southwestern North Dakota with special reference to the coal, by A. G. Leonard; the geology of northeastern North Dakota with special reference to cement materials, by John G. Barry and V. J. Melsted; the geological history of North Dakota, by A. G. Leonard; the Bottineau gas field, by John G. Barry, and a paper on good roads and road materials, by W. H. Clark. The papers in general meet well the purposes for which they are planned and the survey by such a report demonstrates its value to the state. The paper on the geological history of North Dakota could, however, have been improved in a number of particulars.

It was prepared for the use of schools and the general reader, yet there is no statement in it of the fundamental conception that geologic time embraces tens of millions of years. Yet without such discussion the general reader is apt to preserve the inherited notion that time is antediluvian and postdiluvian and the whole embraced in some thousands of years. This, however, is a minor point in comparison with definite errors retained from an earlier period in geology. For example, it is sweepingly stated that "granites are examples of Archean rocks." Whereas they are now known to occur as massive intrusive rocks of any age up to middle Tertiary. Further, it is stated "that the oldest part of the continent, that which was the first to be raised above the sea, was a U-shaped land mass, the two arms of the U enclosing Hudson Bay. At the beginning of the Paleozoic Era by far the greater part of our continent, with the exception of the above land, was beneath the sea." This statement may be compared with Walcott's well-founded conclusions, published in 1891, that the area of the pre-Cambrian Algonkian continent was larger than at any succeeding period until the Mesozoic, and that the Cambrian sea did not begin to invade the great interior continental area until late Middle Cambrian time. It is true that these and other important conceptions have not been properly emphasized in many text-books, but that cannot be regarded as good reason for their further perpetuation. Their importance in geologic theory is, furthermore, such as to warrant calling attention to their occurrence in this report. The idea, however, of publishing in state reports popular expositions of geologic structure and history, as is here done, is a most valuable one from the educational point of view, and one which state surveys have largely neglected.

J. B.

3. *The Figure of the Earth and Isostasy from Measurements in the United States*; by JOHN F. HAYFORD, Inspector of Geodetic Work, and Chief, Computing Division Coast and Geodetic Survey. Pp. 178, plates and figures 17. Washington, 1909.—This report is one of great interest to geodesists and geologists, for though the principal conclusions have been previously published by Hayford, this is the first appearance of the complete work. The author points out that earlier computations upon the elements of the spheroid have regarded the deflections of the vertical as accidental errors, an assumption which is evidently untrue. By considering them as due to the known irregularities in topography largely counterbalanced by the unknown irregularities in subsurface densities, a solution is reached giving the character of the latter, and by thus allowing for constant errors attaining more correct and larger values for the dimensions of the spheroid. By assuming in the solution the existence of certain deficiencies of mass underlying elevated tracts, the weight of the new determination of the terrestrial dimensions becomes 1.7 times that derived otherwise. This may be taken as a mathematical demonstration of isostasy. Hayford furthermore finds that isostatic adjustment is so nearly complete that the deflections of the vertical average are less than a tenth of what they would be if due to topographic irregularities alone and the stress differences in the crust are not more than one-twentieth what they would be if isostasy did not prevail. Consequently the United States is not maintained in its position above sea level by terrestrial rigidity but is in the main buoyed up, floated, in each of its parts, because it is composed of material of deficient but irregular density. The solution further shows that the flotation is not due to a lighter crust resting upon a fluid and denser substratum and that the isostatic compensation is approximately satisfied within a hundred miles of the surface. This report brings forth the results of a monumental labor and its author and the organization which he represents are to be congratulated upon its completion. The results will be most interesting if gravity determinations are now made in order to throw further light upon the variations in subsurface densities extending to the depth at which isostatic compensation becomes complete.

The reviewer would point out that the conclusion, that the various physiographic provinces are now so closely compensated that the unbalanced stresses in the earth are not more than a twentieth as great as they would be if isostatic adjustment did not prevail, is seemingly at variance with the geological evidence that the crust is able to remain unwarped during long periods of time, permitting the wide development of base-leveled surfaces. The reconciliation of these two well-founded conclusions of modern geology is one of the larger problems awaiting solution in the future. Although, as Willis has suggested, the present epoch may be one of unusually complete isostatic adjustment, how comes it that if so complete at present, at other times the crust could for so long have resisted the stresses due to widespread erosion?

J. B.

4. *Geological Survey, Cape of Good Hope*; by A. W. ROGERS, Director; 13th Annual Report, Cape Town, 1908.—The 1908 Report of the Geological Commission contains the following papers: (1) Report on the Geology of parts of Prieska, Hay, Britstown, Carnarvon and Victoria West, by A. W. Rogers and A. L. du Toit; pp. 9–109, figs. 13; (2) The kimberlite and allied pipes and fissures in Prieska, Britstown, Victoria West and Carnarvon, by A. L. du Toit; pp. 111–127, 3 figs.; (3) Notes on a journey to Knysna, by A. W. Rogers; pp. 129–134, 1 plan.; (4) The Tygerberg anticline in Prince Albert, by A. W. Rogers; pp. 135–139. Field work in Prieska and adjoining regions included a study of areas previously mapped, with the result that errors were found to have been made in the determination of structural and stratigraphic relations. This present report, therefore, replaces in large part the report for 1899. (This Journal, xiii, 413.) New occurrences of Dwyka beds are described and petrographic studies have been made of a number of igneous and metamorphic rocks including an unusually large variety of granulites, the origin of which is in doubt. An interesting economic feature is the fact that the water supply is found in decomposed dikes of kimberlite, etc., rather than in the shales and other sedimentaries.

H. E. G.

5. *The Devonian fauna of the Ouray limestone*; by E. M. KINDLE. Bull. 391, U. S. Geol. Survey, 1909; pp. 60, plates 10.—This Upper Devonian fauna characterized by *Plethorhynchia endlichii* and *Spirifer cf. whitneyi* is now known to extend from southern New Mexico to the north line of Colorado. It is composed of 40 species, most of which are restricted to this biota. The strikingly new element is a brachiopod related to *Syringothyris*, for which is here proposed the new generic name *Syringospira*.

The author does well in removing for western faunas the name *Spirifer disjunctus*, but he should have gone a step farther and renamed the so-called *S. whitneyi*, as these Colorado shells are not identical with the typical Iowa individuals. The reviewer has seen the Ouray species also in the Three Forks of Montana and in British Columbia north of the Canadian Pacific Railway. c. s.

6. *Lower Paleozoic Hyolithidae from Girvan*; by F. R. COWPER REED. Trans. Royal Soc. Edinburgh, 47, 1909; pp. 203–222, pls. 3.—From the Ordovician and Silurian beds of the Girvan district the author describes 10 new species of Hyolithes, 4 Orthotheca, 2 Ceratotheca, and 5 Pterotheca. c. s.

7. *Die asiatischen Fusulinen. Die Fusulinen von Darwas*; von GÜNTER DYHRENFURTH. Palæontographica, Band 56, 1909, pp. 137–176, pls. 13–16.—In this work, which is a continuation of Ernst Schellwien's contemplated Monographie der Fusulinen, are described with great care six forms of Fusulina illustrated by many microphotographs. The geologic occurrence is also fully given.

C. S.

8. *Paläozoische Seesterne Deutschlands. I. Die echten Asteriden der rheinischen Grauwacke*; FRIEDRICH SCHÖNDORF, *Paläontographica*, 56, 1909, pp. 38-112, pls. 6-11.—Here are described in detail 12 species of Lower Devonian starfishes of the family Xenasteridæ. These are grouped in the genera *Xenaster* (4 species), *Spaniaster* (1), *Agalmaster* n. gen. (3), *Rhenaster* n. gen. (1), *Trimeraster* n. gen. (1), *Eifelaster* n. gen. (1), and *Asterias*. The drawings are somewhat diagrammatic but illustrate the characters far better than would photographs.

In all the genera the ambulacra are directly opposite one another and do not alternate. The ambulacra and adambulacra are also opposite each other. The mouth opening is bounded by 5 pairs of mouth plates and 5 pairs of slightly modified ambulacra. No ocular plates are preserved, according to the author; the reviewer has seen none in these old starfishes before the time of the Lower Carboniferous. c. s.

9. *La Vallée de Binn (Valais). Étude géographique, géologique, minéralogique et pittoresque*; par LÉON DESBUISSONS. Pp. viii, 324; 51 illustrations, etc. Lausanne, 1909 (G. Bridel & Co.).—This is a popular work on a mineralogical locality which occupies a unique position in the interest of the occurrence and the almost inexhaustible variety of new and rare species which it has afforded. These facts are briefly summarized here, and many illustrations give an admirable idea of the scenery of the valley.

10. *Catalogue of the Fossil Bryozoa in the Department of Geology, British Museum of Natural History*. The Cretaceous Bryozoa, Volume II; by J. W. GREGORY. Pp. xlviii, 346, 9 plates, 75 figures.—The first volume of this catalogue was published in 1899 and the appearance of the present volume has been delayed in consequence of the retirement of the author from the staff of the British Museum. In the years which have intervened a large amount of material has been added to the collections of the Museum, so that the whole work has been expanded and when complete will embrace a third concluding volume. It is expected that this will be shortly prepared by Mr. W. D. Lang, who succeeded Dr. Gregory as Assistant in charge of this section of the Museum.

11. *A Hand-List of the Genera and Species of Birds [Nomenclator Avium tum Fossilium tum Viventium]*; by R. BOWDLER SHAPE. Volume V. Pp. xx, 694.—This volume of the British Museum Handlist of Birds deserves to be especially noted, since it completes a large and most important labor begun in 1898. The author and those who have worked with him deserve the congratulations of zoologists for what they have done in this way to advance the study of ornithology.

12. *Physiologische Pflanzen-Anatomie*; von Dr. G. HABERLANDT. Pp. xviii, 650. Vierte Auflage. Leipzig, 1909 (Wilhelm Engelmann).—This is the fourth and enlarged revision of a very important work. A quarter of a century has passed since Professor Haberlandt, then as now at Graz, published the first

edition. The treatise was recognized from the outset as opening up fresh fields of research on the borders between three allied departments of Botany. The relations which exist between form, function, and origin are sometimes exceedingly obscure, and this obscurity was deepened in many instances by the neglect of some gross morphologists to investigate the minute anatomy of the organs in question. To Schwendener and Haberlandt is due a large part of the credit for stimulating observers to enter upon this middle ground in the right way. The present volume by Haberlandt is in many respects a great improvement upon the previous editions, since it enters more boldly upon the field of æcology and brings up some of the very attractive questions in the domain of what we may term applied physiology. It is truly surprising to notice the small number of changes in the statement of facts which the author has been compelled to make in the period of twenty-five years. The extreme caution which characterized the early edition has borne good fruit in the later ones, since there have been practically no mistakes to recall. The treatise in its enlarged form is of great value to morphologists, anatomists, and æcologists, and, in a general way, to systematists, as well.

The publisher has wisely reprinted as a separate, the pages devoted to the irritable organs of plants, since the subject of sensitiveness is attracting at the present time a good deal of attention. A few physiologists will not agree with some of Haberlandt's conclusions, but even they must admit his fairness and clearness.

G. L. G.

### III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Report of the Secretary of the Smithsonian Institution, Dr. CHARLES D. WALCOTT, for the year ending June 30, 1909.* Pp. 95.—The annual report of the Secretary of the Smithsonian Institution for the year ending June, 1909, has recently appeared. It gives the usual interesting summary in regard to the activity of the Institution in its varied functions. Dr. Walcott draws attention to the fact that in the estimates for the present year there is an increase of \$10,000 for the Bureau of Ethnology, to be used in connection with researches among the tribes of the Middle West and also in Hawaii and Samoa. A larger appropriation is also called for to carry on the work of the Astrophysical Observatory, for the Zoological Park, and particularly for the new building of the National Museum, which is now nearing completion. In regard to the latter it is stated that the entire stone work of the outer walls is completed, as also the roofs and skylights, and much progress has been made in the interior, that it was expected that some of the halls and work-rooms would be ready for use early in the autumn (1909). The International Tuberculosis Congress, in the autumn of 1908, utilized

for its meetings and exhibitions a large part of the first and second floors. A full statement in regard to the National Museum as a whole is given by Dr. Rathbun in the volume noted below.

A brief summary is given of the first accessions to the Museum from the Roosevelt expedition in Africa. The results have been even more important than anticipated, including many excellent specimens, particularly of the skins of the larger mammals. Special funds were provided by friends of the Institution to pay for the outfit and expenses of the naturalists who accompanied Col. Roosevelt, while his own expenses, with those of his son, have been met by himself. Mr. W. W. McMillan of Juja farm near Nairobi, East Africa, has presented an exceptionally fine collection of living African animals.

Of other scientific work carried out under the auspices of the Institution may be mentioned the continued explorations by the Secretary, Dr. Walcott, in Montana and the Canadian Rockies, having as their object the study of Cambrian geology and paleontology. Professor J. P. Iddings is now carrying on researches on a Smithsonian grant in Japan, Eastern China, and Java. Miss Alice Eastwood, also as the result of a grant, has re-collected the botanical species from the region of Santa Barbara secured by Thomas Nuttall in 1836. Under the Hodgkins fund several investigations have been prosecuted. The statements in regard to the Library, the Gallery of Art, the Zoological Park, etc., are all interesting, but cannot be summarized here. As usual, Mr. C. G. Abbott, director of the Astrophysical Observatory, gives a summary of the work carried on under his direction at Washington, at Mt. Wilson, and on Mt. Whitney.

2. *Annual Report of the Board of Regents of the Smithsonian Institution, showing the Operations, Expenditures, and Condition of the Institution for the Year ending June 30, 1908.* Pp. x, 801, with 23 plates, 25 figures, and 4 charts.—The Secretary's Report, which forms the opening portion of this volume, was noticed a year since (see vol. xxvii, p. 196). The general Appendix (pp. 113–801) contains as usual a large series of papers on scientific subjects, covering many lines of scientific activity and discovery. No more well-selected and useful presentation of recent scientific memoirs, in a form to interest the intelligent public, can be found in a single volume. The opening paper is devoted to aeronautics and is profusely illustrated; aviation in France and wireless telephony follows, then phototelegraphy, and the gramophone; while on the Natural History side we find reproduced (from this Journal, xxv, 169) the important paper by Dr. Lull on the Evolution of the Elephant, with another on Angler Fishes by Dr. Gill. The volume closes with several biographical papers.

Recent publications from the Smithsonian Institution are noted in the following list:

Report on the Progress and Condition of the U. S. National Museum for the year ending June 30, 1909. Pp. 141.—This is a full and very interesting account of the Museum, its buildings,

collections, and library, by Dr. RICHARD RATHBUN, Assistant Secretary of the Smithsonian Institution.

The National Gallery of Art : Department of Fine Arts of the National Museum ; by RICHARD RATHBUN. Pp. 140, 26 plates.—Dr. Rathbun has given here a full history of the development of the department of Fine Arts in the National Museum, begun in 1840. The bequest of Mrs. Harriet Lane Johnston in 1903 and the gift of Mr. Charles L. Freer of Detroit have given the National Gallery a notable position in the country ; a suitable building for its preservation must be provided later. The concluding chapter of this volume gives a preliminary catalogue of the collection with numerous reproductions of important pictures.

Bureau of American Ethnology, Bulletin 38. Unwritten Literature of Hawaii. The Sacred Songs of the Hula ; collected and translated, with notes and an account of the Hula ; by NATHANIEL B. EMERSON. Pp. 288, 24 plates, 3 figures.

Bulletin 39. Tlingit Myths and Texts ; recorded by JOHN R. SWANTON. Pp. viii, 451.

Bulletin 41. Antiquities of the Mesa Verde National Park : Spruce-Tree House ; by JESSE WALTER FEWKES. Pp. 57, 21 plates, 37 figures. Washington, 1909.

Bulletin 42. Tuberculosis among certain Indian Tribes of the United States ; by ALES HRDLICKA. Pp. vii, 48, 22 plates.

3. *National Antarctic Expedition, 1901-1904. Magnetic Observations.* Prepared under the Superintendence of the Royal Society. Pp. vii, 274 ; 13 figures, and 43 plates, map and sketches. London, 1909.—The earlier volumes containing the records of the Antarctic Expedition of 1901-1904, under Captain R. F. Scott, R. N., have already been noticed in this Journal (xxvi, 588 ; xxvii, 271) ; that on Physical Observations included a report on a portion of the magnetic work. The present volume completes this subject, giving detailed tables of hourly values of the magnetic elements with an exhaustive discussion of the same. Dr. Charles Chree of the Kew Observatory has taken an important part in the elaboration of the observations.

Among the special topics discussed may be mentioned a comparison of Antarctic disturbances and the aurora, and also an examination of disturbances simultaneous in the Antarctic and Arctic, from October, 1902, to March, 1903, by Prof. Kr. Birke-land. The sketch map which forms the frontispiece shows a portion of the coast of South Victoria land with the winter quarters of the "Discovery" on Ross Island. On it are noted the positions of the south magnetic pole as given by three successive recent expeditions. The close agreement between these, the distance varying from a maximum of about 80 miles to a minimum of about 40 miles, is particularly noteworthy. The latitude and longitude of these three positions are as follows :

Position found by the	"Southern Cross,"	Lat. 72° 40' S	Long. 152° 30' E
" " " "	"Discovery,"	72° 51'	156° 25'
" " " "	Lieut. Shackelton,	72° 25'	155° 16'

4. *The Evolution of Worlds*; by PERCIVAL LOWELL. Pp. xiii, 262. New York (The Macmillan Co.).—This book is a revised edition of lectures delivered in February and March, 1909, before the Massachusetts Institute of Technology, in which institution the author is non-resident professor of astronomy. The lectures present the most recent facts and speculations regarding the past and future of the Solar system, illumined by the play of the author's active imagination and colored by an astonishing vividness of language. We do not remember to have met in any of Dr. Lowell's previous essays any such freedom in the use of English. Some of the theories which he explains are startling, but the language in which they are set forth is much more so. If we all permitted ourselves such liberties with our mother tongue it would speedily descend to a chaos and darkness such as Dr. Lowell predicts for the solar system itself.

We quote at random from the first few pages.

"Unimpressing our senses," "grandiose vicissitudes spectrally revealed," "stars cuticle," "ambidextrous impartiality of space," "The culmination of Coalition"—"the acme of accretion."

But such mishandling of language, though it irritates the reader and mars his enjoyment, does not vitiate the logic or destroy the substance of the book.

The first two chapters, entitled "Birth of a Solar System," and "Evidences of the Initial Catastrophy," will excite most interest. The author considers that the initial stage of our solar system, or rather the beginning of the cycle of change through which it is now passing, was that of a spiral nebula. From this the present order arose and to it in some distant age and region it may again return, to repeat the cycle indefinitely. Such an enormous program, which explains everything but the origin of matter and provides for its eternal activity, satisfies the mind and makes us wishful that it may be true.

Space forbids a discussion of it further than to say that the spiral form in a nebula is held to be due to action from without rather than from within, in fact to a tidal disruption caused by the passage of a large body close to the previously quiescent mass. Thus an old and worn out sun may be torn up within a few days into a meteoric nebula, heated by collisions of its fragments and developing under gravity into a planetary system.

W. B.

5. *Hyperbolic Functions*, prepared by GEORGE F. BECKER and C. E. VAN ORSTRAND. Pp. li, 321. Smithsonian Mathematical Tables, No. 1871. Washington, 1909.—In the systematic study of mathematics hyperbolic functions do not receive the attention which their practical importance as a tool of investigation warrants. Invented or first employed by Mercator in the development of his system of projection, on which to this day all deep sea navigation depends, they have come to play an important part in many branches of applied mathematics. Thus in physics whenever an active entity is extinguished or absorbed (e. g. light, velocity, radio-activity) the decay is represented by some form of



hyperbolic function. Mechanical strains also are most simply expressed in this form. Hence the study of geological deformations always requires the use of these functions; and it is for this reason that the overseers of the U. S. Geological Survey, Messrs. Becker and Van Orstrand, have prepared this most complete and scholarly treatise.

The book has a two-fold value. The tables, eight in number, furnish everything that a worker with hyperbolic functions can need, and they are preceded by an admirable exposition of the theory of hyperbolic function. The subject is developed both from an analytic and independently from a geometrical basis and the relation to elliptic functions is described and also the connection with the geometry of the pseudo sphere. An historical sketch adds greatly to the breadth of view of the subject and fifteen pages are given to formulas which the writers designate as "those most likely to be needed by computers."

This description should make it evident that the book furnishes the most satisfactory treatise on this subject that has hitherto been published.

W. B.

6. *Robbins's Plane Trigonometry*; by EDWARD R. ROBBINS. 8vo, pp. xiii, 153. New York (American Book Company).—A book well adapted for the secondary school course. It represents the experience of a mature and careful teacher whose first object is to get the essentials of the subject into the head of the average boy as quickly and firmly as possible. The learner is introduced to the solution of trigonometric equations sooner than usual, in fact in the first chapter, but the treatment of identities is postponed until quite late for the reason that the author aims to give his followers strength and courage for the assault of this formidable enemy of the weak trigonometer. The distinction between an identity and an equation, however, is not explicitly stated.

W. B.

7. *Experimental Dairy Bacteriology*; by H. L. RUSSELL and E. G. HASTINGS. 147 pages; illustrated. Boston 1909 (Ginn and Co.).—The purpose of this book is to present an elementary course in general dairy bacteriology. Though brief and somewhat limited in its scope, it is complete in itself. The sources of milk contamination, the biological changes that take place in milk, with methods of identifying milk bacteria, the preservation of milk, butter-making, cheese, and milk as a vehicle of disease, are some of the important topics discussed. A thorough mastery of the book should enable the student to pursue intelligently more advanced work in connection with the problems of dairy bacteriology or dairy manufactures.

L. F. R.

8. *Bref och Skrifvelser af och till Carl von Linné*; af TH. M. FRIES. Pp. iv, 342. Stockholm, 1909.—This third part of the first volume of the correspondence of Linnaeus contains letters Nos. 459 to 573; they are arranged alphabetically, according to the names of the recipient or writer, from A to B. This important publication is being carried on under the auspices of the University of Upsala, and the librarian of the University asks that any persons possessing letters of Linnaeus communicate with him on the subject.

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